

Sequence Stratigraphy - Introduction

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"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



Sequence Stratigraphy : Books

Catuneanu, O., 2006: Principles of Sequence Stratigraphy. First Edition, Elsevier, Amsterdam, 375 pp

Sam Boggs, Jr, 2006: Principles of Sedimentology and Stratigraphy, 4th edition, Prentice Hall, 662 pp

Donald R. Prothero, and Fred Schwab, 2003 :Sedimentary Geology, An Introduction to Sedimentary Rocks and Stratigraphy, 2nd edition, W. H. Freeman; 600 pp



Sequence Stratigraphy

A framework of **genetically** related (accumulated in the same “general” depositional setting) stratigraphic facies **geometries** defined by **bounding surfaces** (formed by major changes in depositional regime) used to **determine depositional setting**

Sequence Stratigraphy

- ⇒ Is the identification of a framework of sedimentary packages:
 - Sequences
 - Parasequences, or
 - Cycles
- ⇒ These represent a genetically related (e.g. they accumulated in the same "general" depositional setting or regime) cycle of deposition of stratigraphic facies geometries
- ⇒ The packages accumulate as the result of:
 - Base level change (induced by sea level & tectonic change so allocyclic)
 - Point source migration (autocyclic), or
 - Mass transport events (autocyclic)
- ⇒ Defined by bounding surfaces (of erosion or deposition) (formed by major changes in depositional regime) (often Hydraulic Jumps tied to base level change or changes in rates of sediment supply).
- ⇒ Used in conjunction with, the architectural stacking patterns of the packages, Walters Law (vertical and lateral arrangement of lithology, sedimentary structures, and biostratigraphy) to determine depositional setting and predict the distribution of lithofacies

Book Cliffs – Prograding Cretaceous Shoreline

Use a framework of genetically related stratigraphic facies geometries and their bounding surfaces to determine their depositional setting

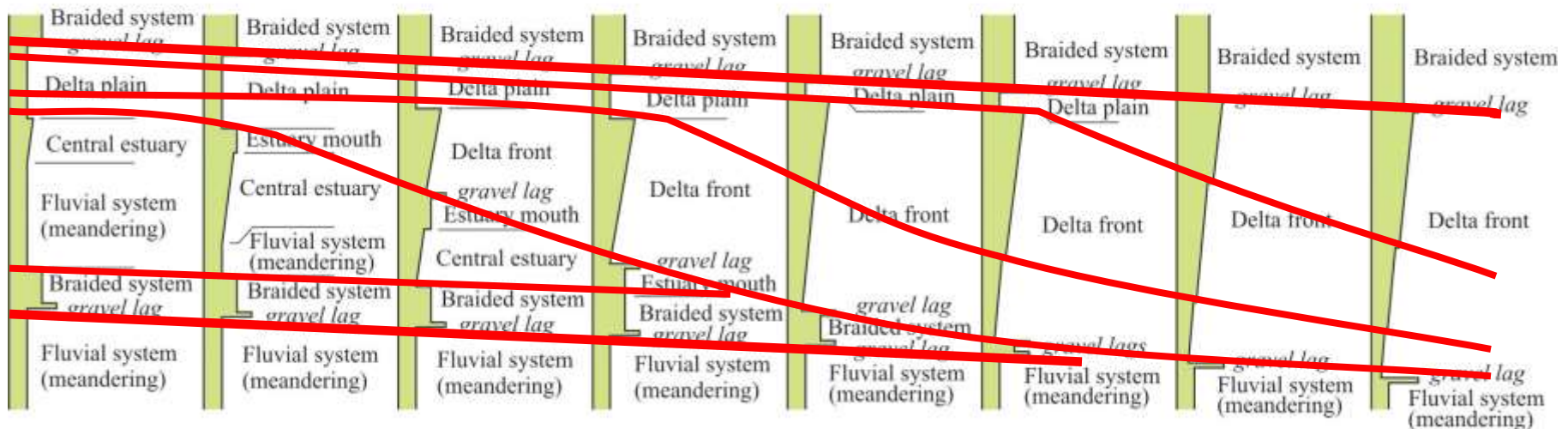


Photo by Torbjörn Törnqvist

Book Cliffs – Prograding Cretaceous Shoreline

Use a framework of genetically related stratigraphic facies geometries and their bounding surfaces to determine their depositional setting

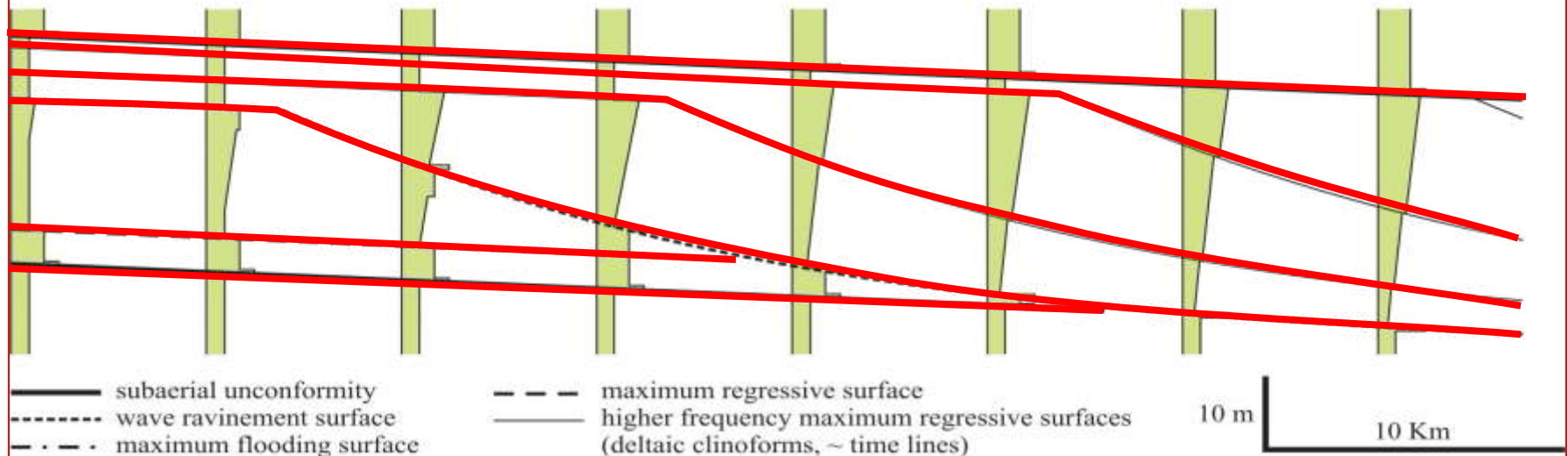
1. Data: vertical profiles and paleo-environments



Book Cliffs – Prograding Cretaceous Shoreline

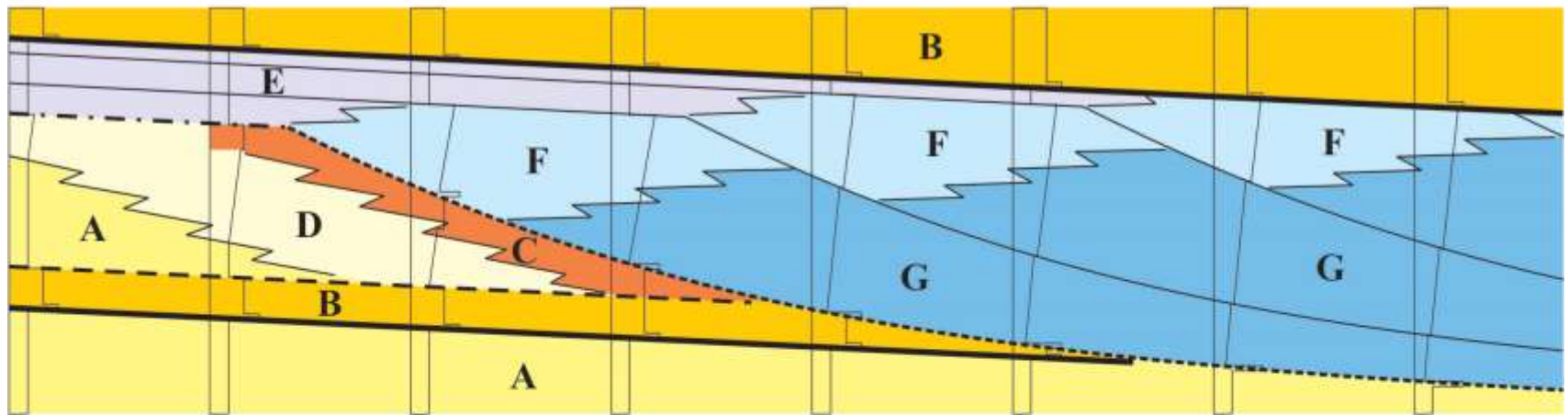
Use a framework of genetically related stratigraphic facies geometries and their bounding surfaces to determine their depositional setting

2. Sequence stratigraphic framework

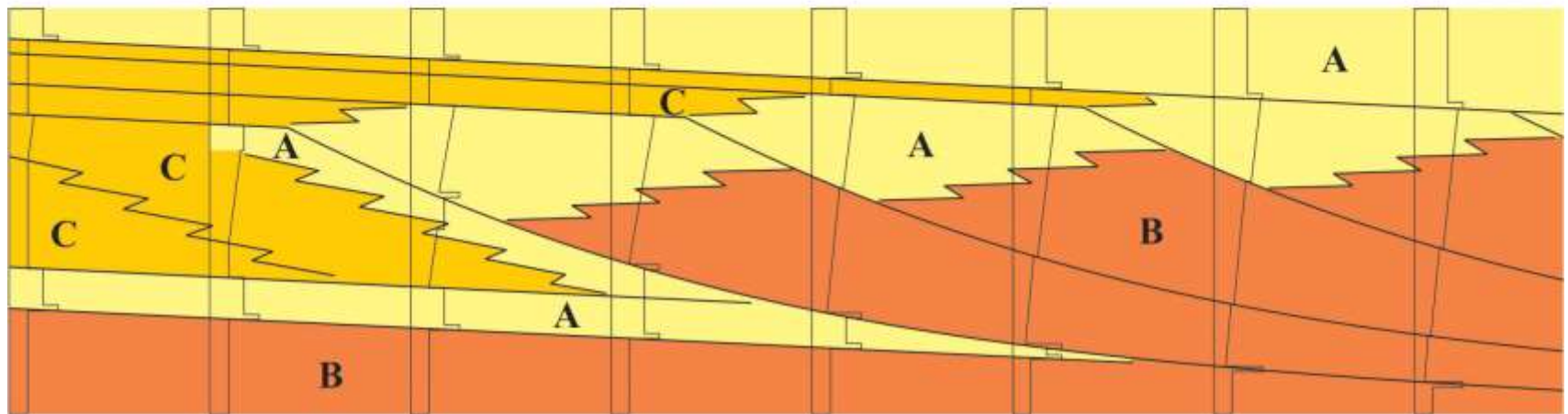


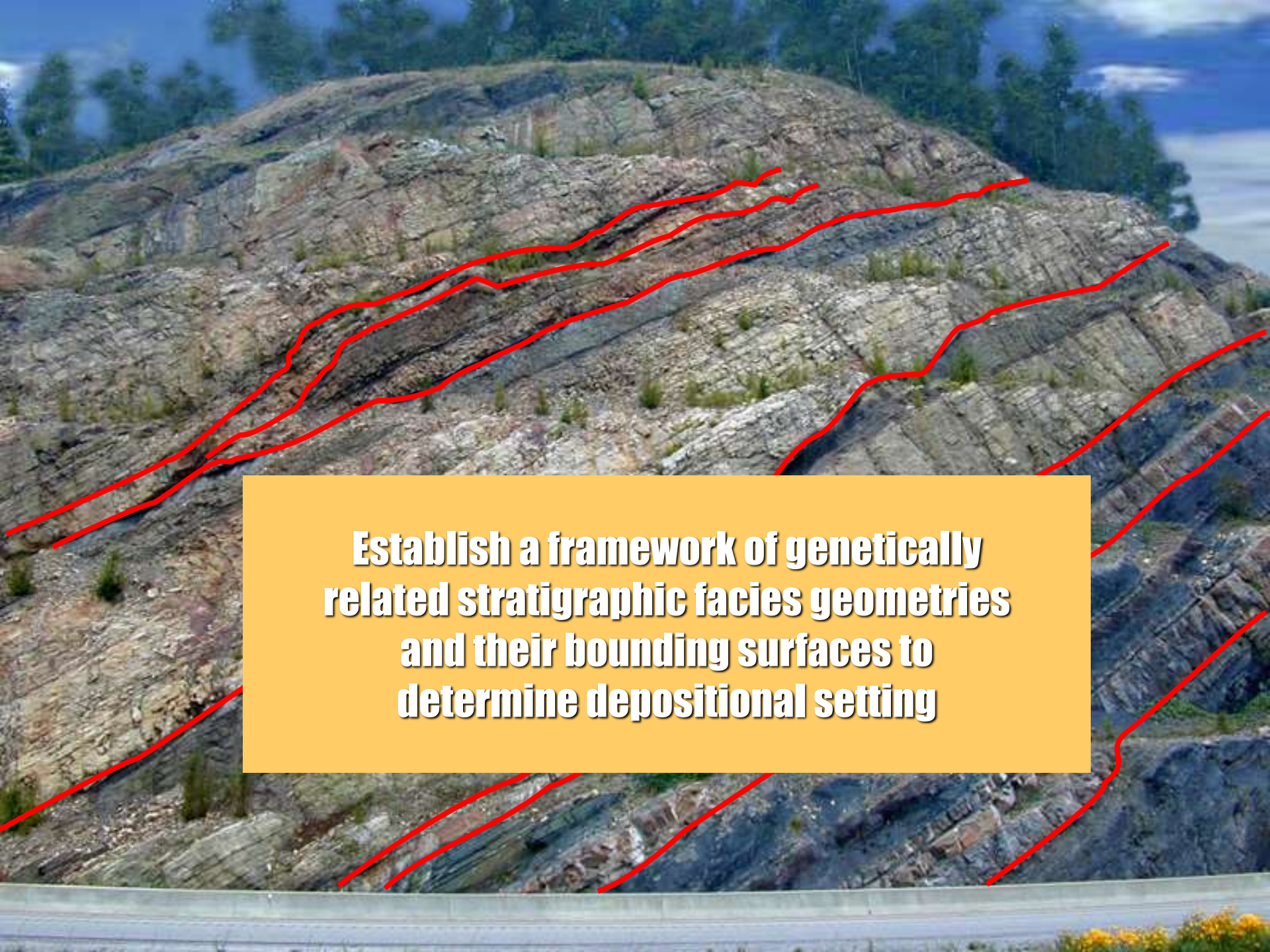
Book Cliffs – Prograding Cretaceous Shoreline

3. Sequence stratigraphic framework, facies contacts, and paleo-depositional environments



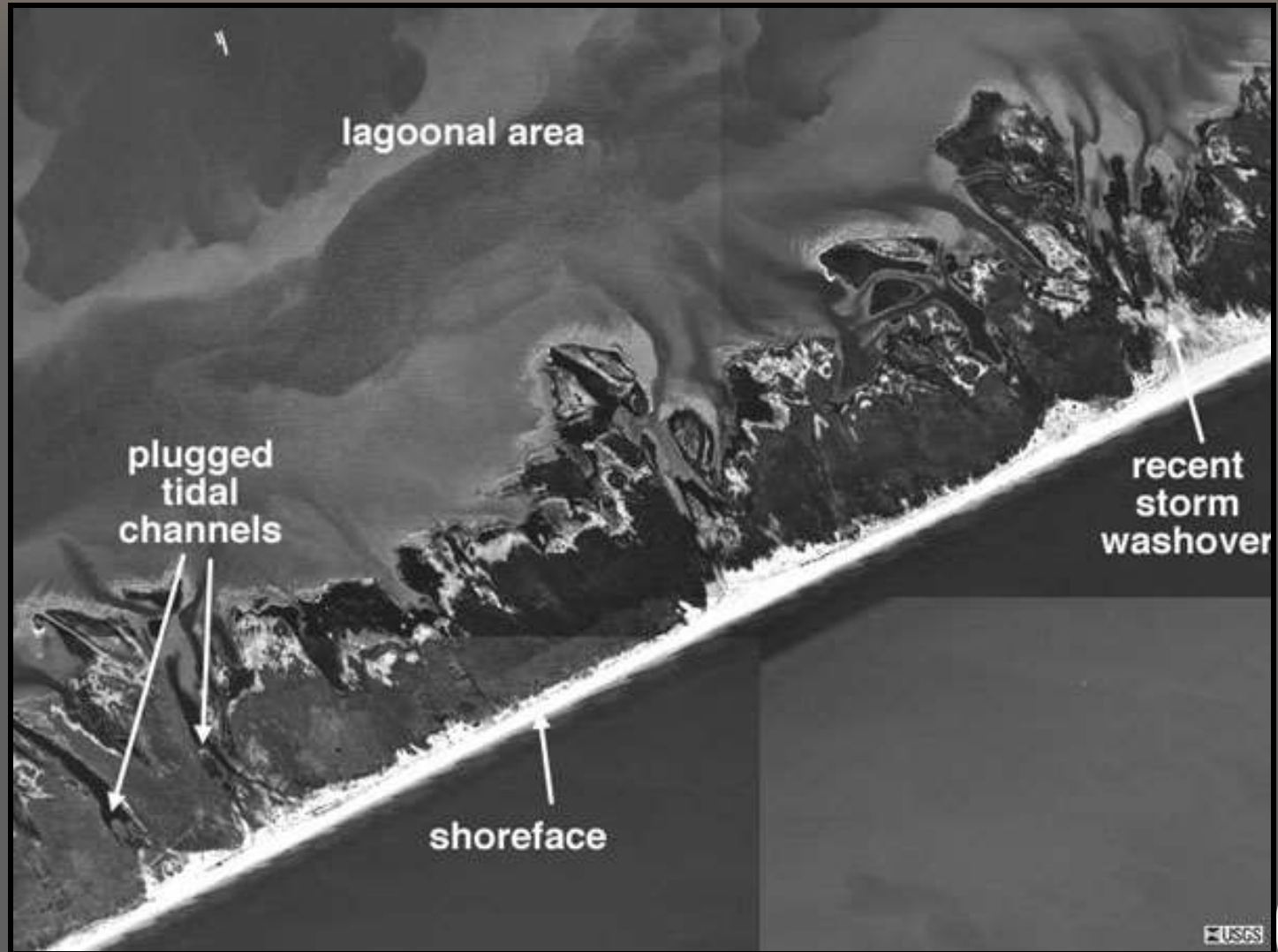
4. Cross-section emphasizing lithostratigraphic units





Establish a framework of genetically related stratigraphic facies geometries and their bounding surfaces to determine depositional setting

Barrier Island



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Sequence Stratigraphy

Interpretation involves:

- ⇒ Identify subdividing "**surfaces**" enveloping "**discrete sediment body geometries**" of sedimentary section.
- ⇒ **Backstrip** geometries from oldest to youngest
- ⇒ **Reassemble** these in order of formation, using subdividing surfaces, geometry, lithofacies & fauna to interpret the evolving character of depositional setting
- ⇒ Remember:-

"Each stratal unit is defined and identified only by physical relationships of the strata, including lateral continuity and geometry of the surfaces bounding the units, vertical stacking patterns, and lateral geometry of the strata within the units." (Van Wagoner et al., 1990).

Sequence Stratigraphy

- ⇒ The surfaces subdividing sedimentary section are fundamental to sequence stratigraphic interpretation
- ⇒ As understanding of sedimentary systems & interpretation improves nomenclature of each surface can change
- ⇒ Changes in nomenclature often confuse a scientific methodology over laden with complex multi-syllable terms
- ⇒ Surface can be given names used before for different surface
- ⇒ Innocent geologists, not knowing terminology has been changed & lacking understanding of reason for change, may feel they are going stark staring mad

Sequence Stratigraphy

Subdivision & interpretation of sedimentary record using a **framework surfaces** seen in outcrops, well logs, & 2-D and 3-D seismic.

Include:

- ⇒ **Surfaces of erosion & non-deposition (Sequence Boundaries, Forced Regression Erosion Surface, Regressive Surface of Marine Erosion)**
- ⇒ **Flooding (Transgressive Surfaces [TS or Max Regressive Surface] &/or maximum flooding surfaces [mfs] Ravinement Surfaces [RS- transgressive]**

This framework used to predict the extent of sedimentary facies geometry, lithologic character, grain size, sorting & reservoir quality

Sequence Stratigraphy

Subdivision & interpretation of sedimentary record using a framework **surfaces** seen in outcrops, well logs, & 2-D and 3-D seismic.

Include:

- ⇒ Surfaces of erosion & non-deposition (**sequence boundaries**)
- ⇒ Flooding (**transgressive surfaces [TS] &/or maximum flooding surfaces [mfs]**)

This framework used to predict the extent of sedimentary facies geometry, lithologic character grain size, sorting & reservoir quality

"Sequence Stratigraphy – Basics"

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Lecture Series Overview

- ⇒ Sequence stratigraphy & stratigraphic surfaces
- ⇒ Basics: Ideal 'sequence' of Vail et al 1977 & associated terminology
- ⇒ Clastic system response to changing sea level and rates of sedimentation - with movie
- ⇒ Carbonate systems response to changing sea level and rates of sedimentation - with movie
- ⇒ Exercises – Sequence stratigraphy of carbonates and clastics from chronostratigraphy, seismic, outcrop and well log character



Sequence Stratigraphy

Subdivision & interpretation of sedimentary record using a framework **surfaces** seen in outcrops, well logs, & 2-D and 3-D seismic.

Include:

- ⇒ Surfaces of erosion & non-deposition (**sequence boundaries**)
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"Sequence Stratigraphy – Basics"

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Lecture – Points to Note

- ⇒ Sequence are subdivided by
 - Maximum Flooding Surfaces (mfs)
 - Transgressive Surfaces (TS)
 - Sequence Boundaries (SB)
- ⇒ Arrangement of vertical succession or stacking patterns of unconfined sheets
 - Prograde (step seaward)
 - Retrograde (step landward)
 - Aggrade (build vertically)
- ⇒ Sheets and unconfined lobes containing
 - Non-amalgamated bodies
- ⇒ Incised topographic fill
 - Amalgamated, multi-storied bodies (e.g. incised valleys)
 - Within unconfined lobes

Lecture Outline

- ⇒ Principles of Steno
- ⇒ Bedding Planes - How they form and significance with respect to time
- ⇒ Branches of Stratigraphy - Lithostratigraphy, Allostratigraphy, and Sequence Stratigraphy
- ⇒ Events
- ⇒ Sequence stratigraphic subdividing boundaries
- ⇒ Clastic Sequence Stratigraphic Hierarchy
- ⇒ Carbonate Sequence Stratigraphic Hierarchy



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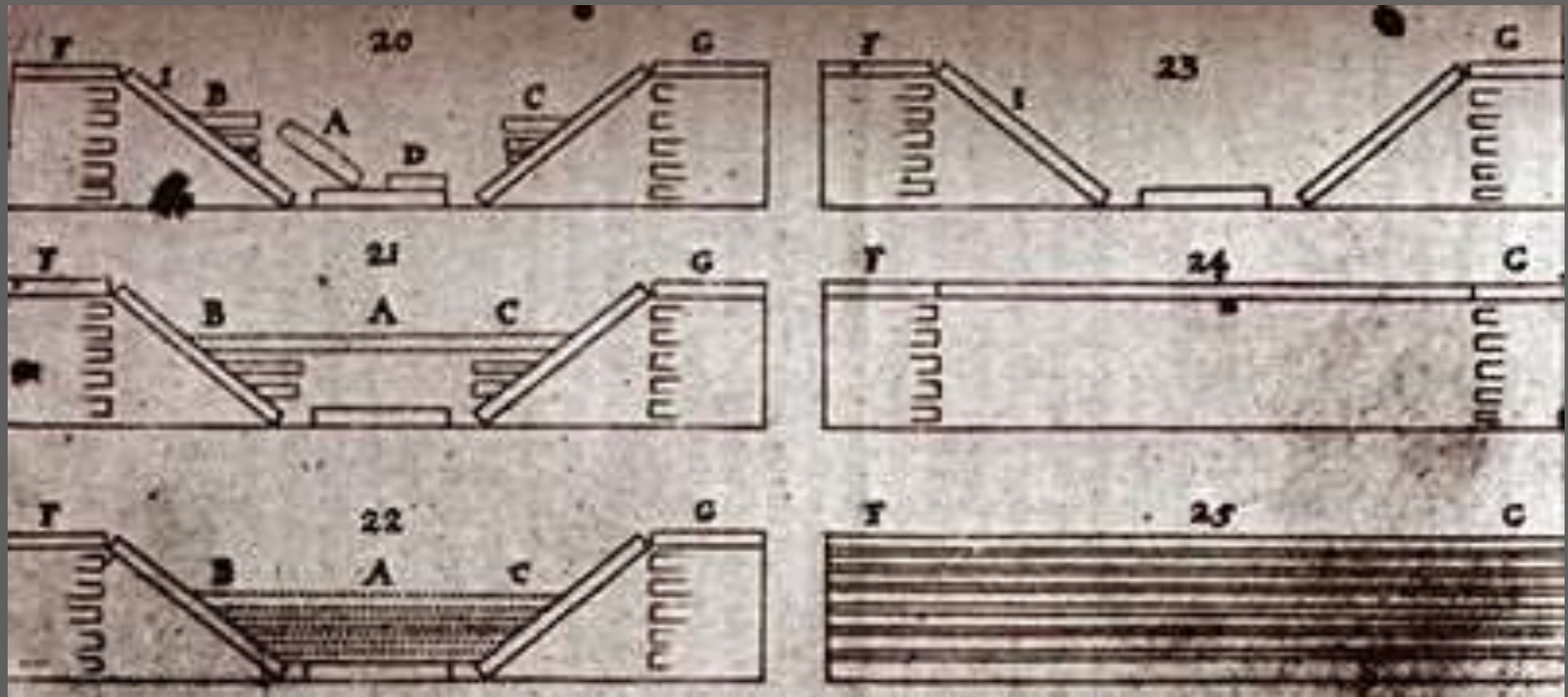


Principles of Steno

- ⇒ **Superposition: a succession of undeformed strata, oldest stratum its at base, with successive younger ones above. Establishes relative ages of all strata & their contained fossils**
- ⇒ **Original horizontality - stratification originally horizontal when sedimentary particles settled from fluids under influence of gravity, so if steeply inclined must have suffered subsequent disturbance**
- ⇒ **Original lateral continuity-strata originally extended in all directions until they thinned to zero or terminated against edges of original basin of deposition**



Steno's Principles



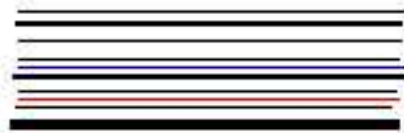
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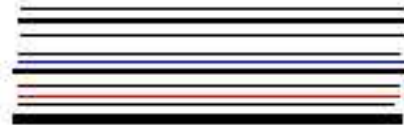
Steno's Three Principles
(Nicholas Steno 1669)

Conceptual starting points:

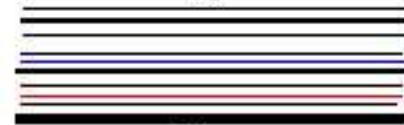
Original lateral continuity



Original horizontality



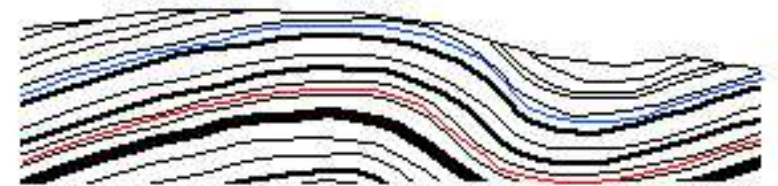
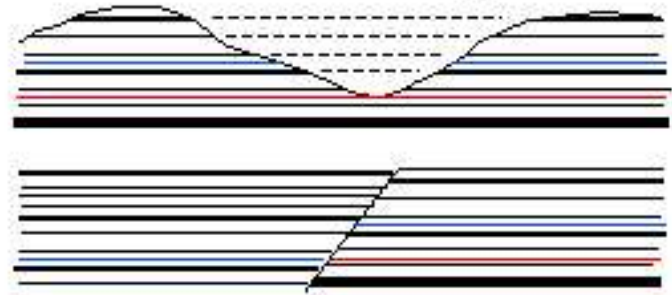
Superposition
(younger over older)



Youngest of layers shown

Oldest of layers shown

Structures observed in layered rocks



So how do the things on the left become the things on the right?

After Bruce Railsback, 2002

Introduction to subdividing surfaces

Range from

- ⇒ High frequency surfaces define **beds**
- ⇒ Lower frequency surfaces define **parasequences** (genetically related cycles or packages of sediment)
- ⇒ Lowest frequency major subdivisions in sedimentary section - the **sequence**



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Bounding surfaces & their definition

Internal and external surfaces of any

- ⇒ Bed
 - ⇒ Parasequence
 - ⇒ Stratigraphic Sequence
- 

Products of unique associations of processes.



Bedding Planes

- ➔ Beds are enclosed or bounded by sharply defined upper & lower surfaces or bedding planes.
- ➔ These surfaces are easiest physical features of sedimentary rocks to identify in outcrop
- ➔ Subdivide successions of sedimentary rock into beds
- ➔ Used to determine relative order & timing of accumulation of sediments forming beds
- ➔ Character of bedding planes, be they eroded, cemented, bored, bioturbated, or depositional surfaces used to aid in interpretation of sedimentary rocks.



Bedding Planes

- ⇒ **Most probably formed by erosion of unconsolidated sediment collected at sediment surface. Weight of sediment, just beneath sediment surface, causes sediment to dewater, compact & become cohesive**
- ⇒ **Less cohesive sediment of surface truncated & expose surface of firmer cohesive sediment below at bedding plane surface in response to:**
 - **Storm waves**
 - **Fast flowing currents of water (say in tidal or fluvial channels)**
 - **Turbid flow of a density current**



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Animated Gif
-
***Bedding
Plane
Development***

-
***Christopher
Kendall***

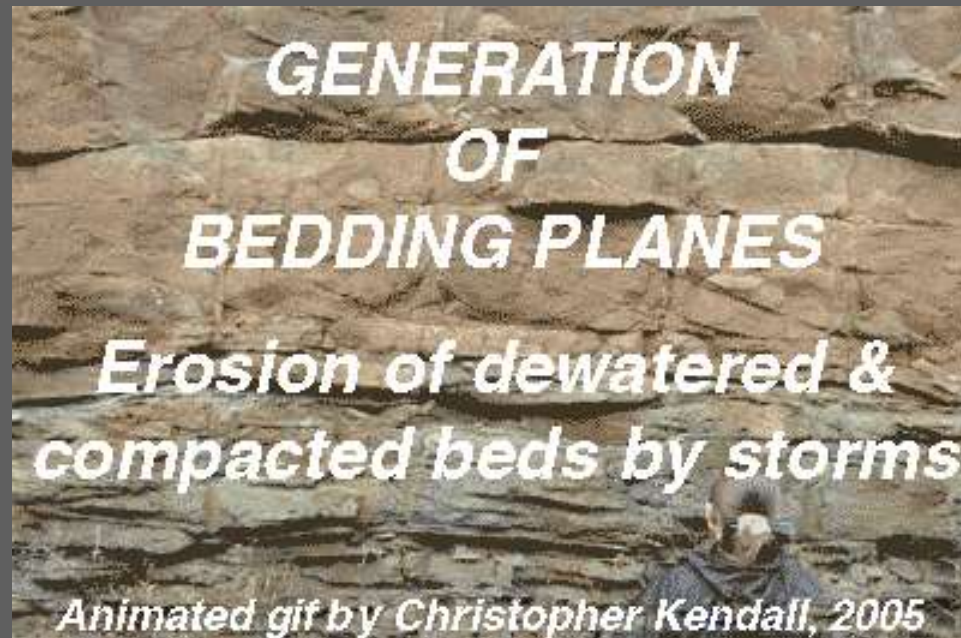
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2005



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Bedding Planes



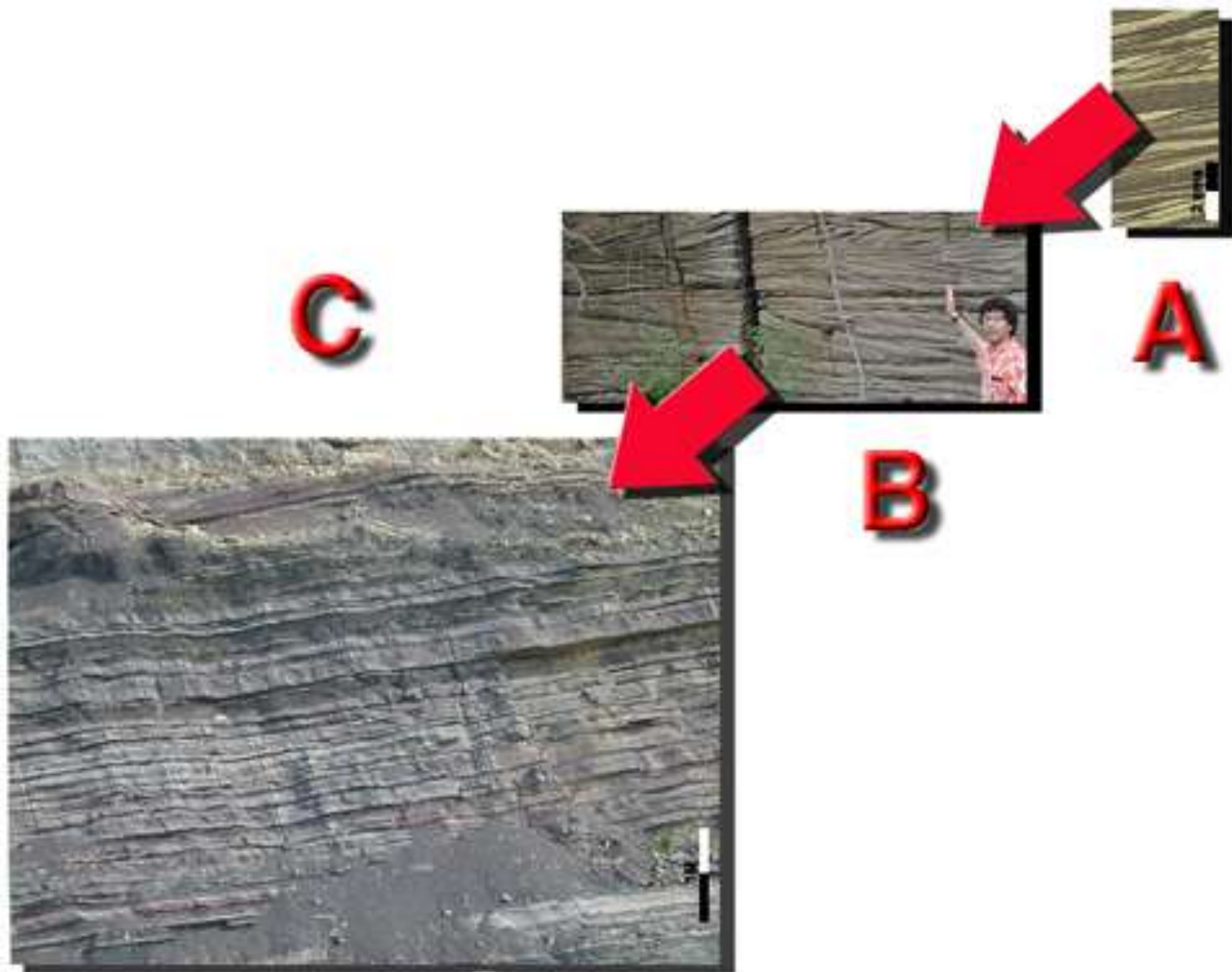
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Link between time, surfaces & layers

- ⇒ **Sedimentary layering of a stratigraphic section has a vast array of dimensional hierarchies**
- ⇒ **Range from units millimeters thick that might be formed over seconds to thousands of feet thick and formed of millions of years**
- ⇒ **Each layer no matter its dimension and whatever the time involved in its deposition, is bounded by surfaces that transgress time**

Link between time, surfaces & layers



Beach Foreshore and Backshore



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Link between time, surfaces & layers

- ⇒ **Foreshore swash units millimeters thick might have formed over seconds but preserve events the collectively formed over weeks to months**
- ⇒ **Each layer no matter its dimension and whatever the time involved in its deposition, is bounded by surfaces that transgress time**

Beach Backshore

Low Angle Swash Events



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Bounding surfaces & their definition

Internal and external surfaces of any

⇒ Bed

⇒ Parasequence

⇒ Stratigraphic Sequence



Products of unique associations of processes.



Bounding surfaces & their definition

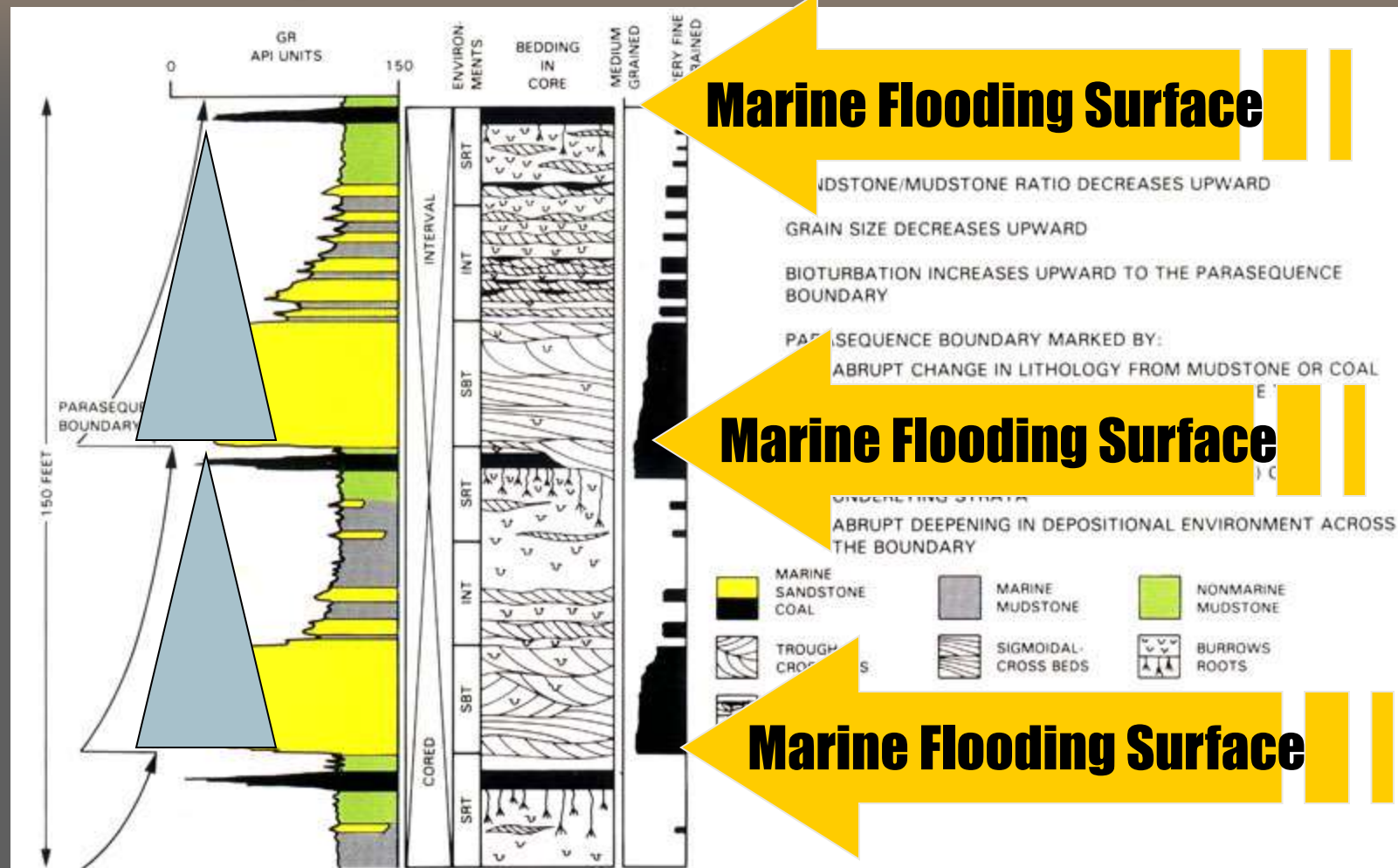
Parasequence is a relatively conformable succession of genetically related beds or bedsets (within a parasequence set) bounded by **marine flooding surfaces** or their correlative surfaces (Van Wagoner, at SEPM's 1985 Midyear Meeting).



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Bounding surfaces & their definition



Stratal characteristics of two upward-fining parasequences. These parasequences are interpreted to form in a tidal flat to subtidal setting on a muddy, tide-dominated shoreline (after Van Wagoner et al, 1990).

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Walther's Law

⇒ "Facies adjacent to one another in a continuous vertical sequence also accumulated adjacent to one another laterally".

- Applies only to a section with no unconformities.
- Applies to a section without subdividing diachronous boundaries, including transgressive surfaces (TS) and the maximum flooding surfaces (mfs).

The interpretation of depositional setting for a section cut by diachronous surfaces must contravene Walther's Law

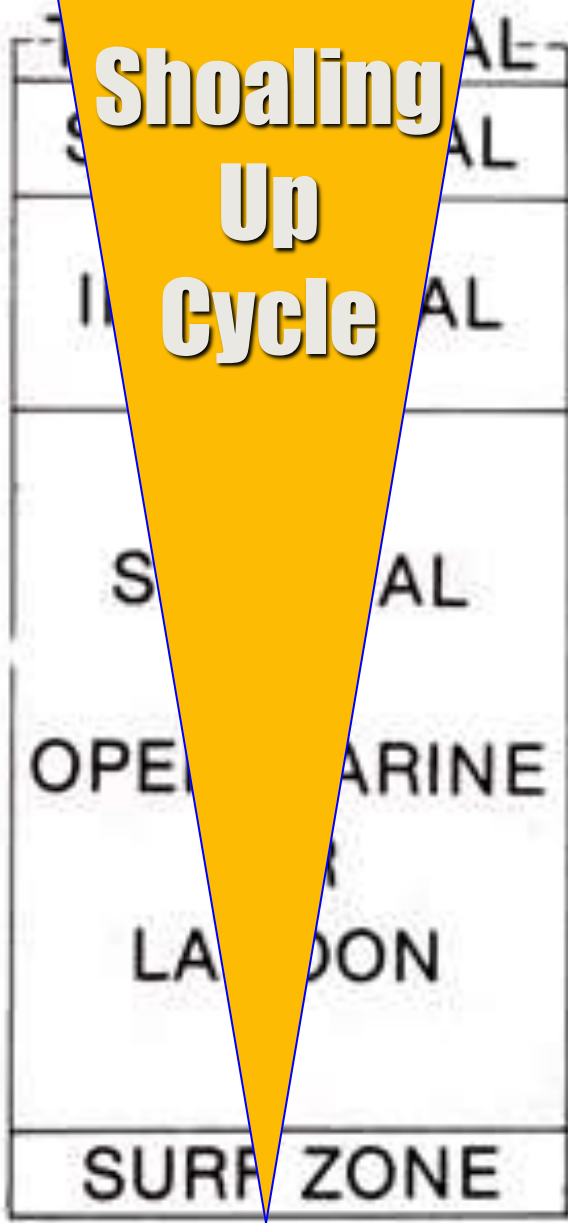
Shelf Cycle James

-

**Vertical
Association
Accumulated
Laterally**



E
D
C
B
A

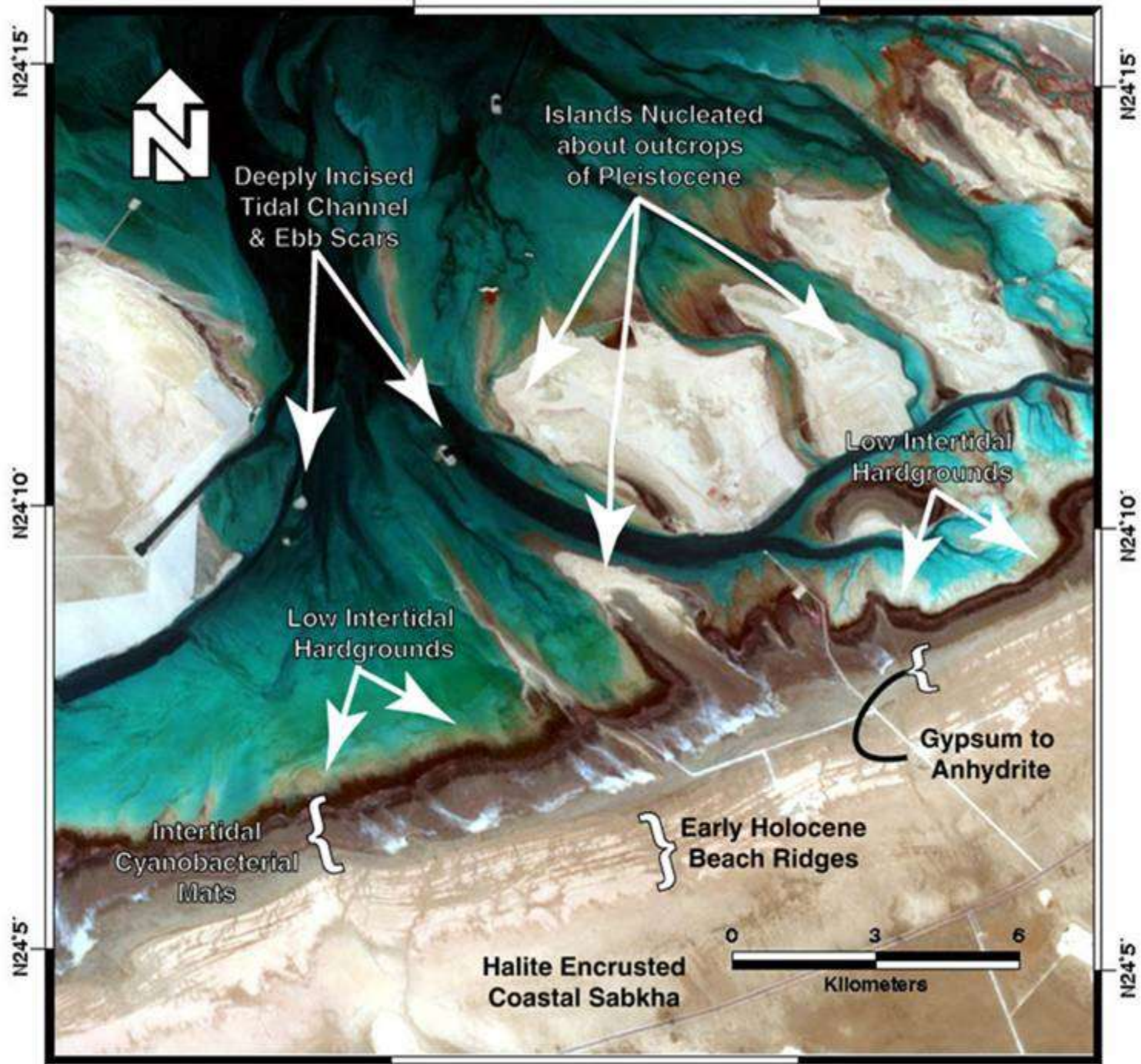




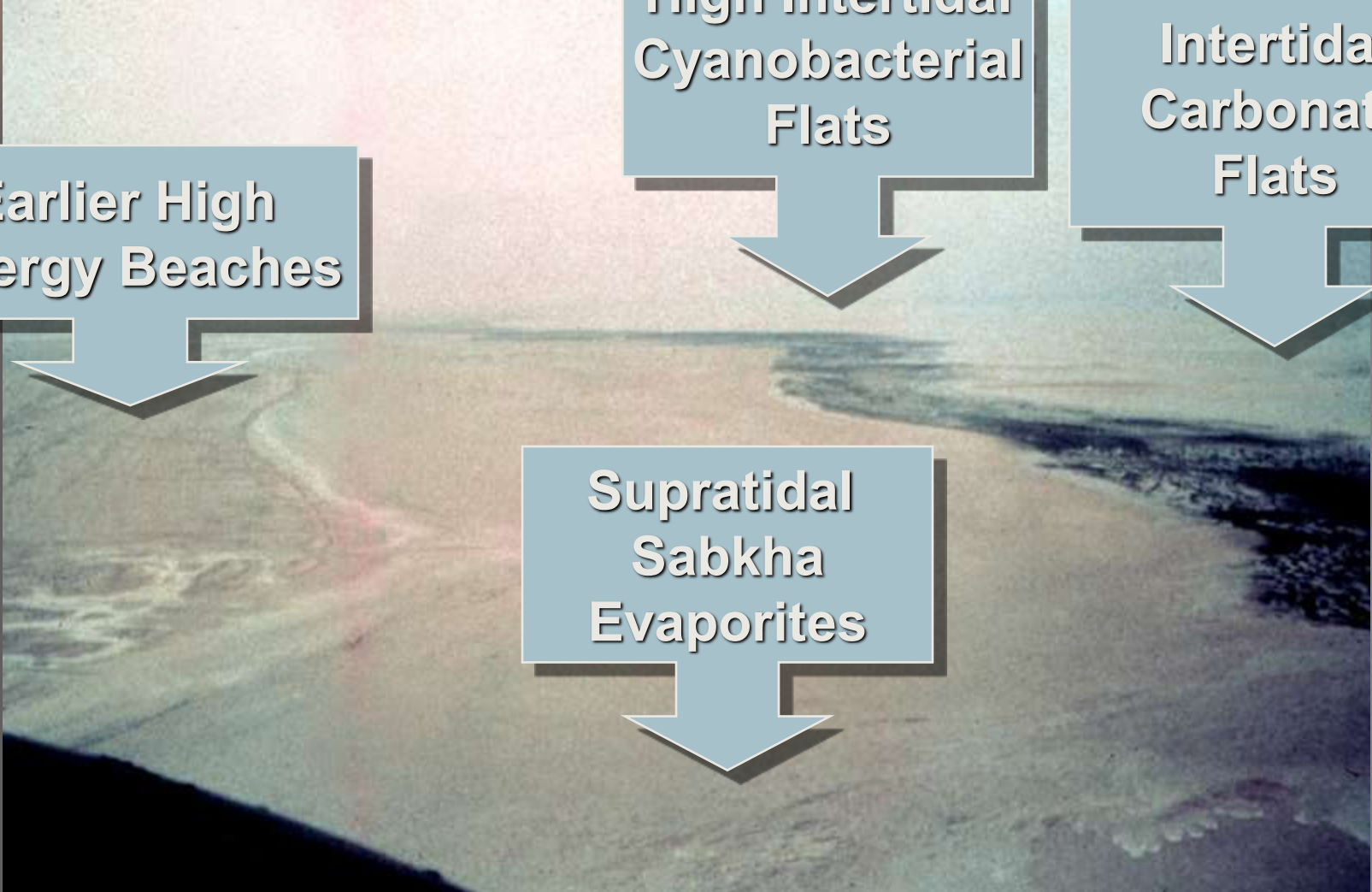
Major coastal provinces of United Arab Emirates & bathymetry of Southern Arabian Gulf in fathoms (modified from Purser, 1973).

Western Coast of the United Arab Emirates





**Earlier High
Energy Beaches**



**High Intertidal
Cyanobacterial
Flats**

**Intertidal
Carbonate
Flats**

**Supratidal
Sabkha
Evaporites**



Intertidal Sand
& Mud Flats

Tidal Channels

Hardgrounds

Beach Ridges

Cyanobacterial
Mats

Sabkha

KEY

- Tidal Channels
- Sand Flats
- Hardgrounds
- Algal Flat
- Sabkha
- Beach Ridges
- Roads

C. G. St.C. Kendall 2003



Or may be not?



Link between time, surfaces & layers

- ⇒ **Each layer no matter its dimension and whatever the time involved in its deposition, is bounded by surfaces that transgress time**
- ⇒ **The interpretation of depositional setting for a section cut by diachronous surfaces must contravene Walther's Law**
- ⇒ **However we simplify this by assuming the**
 - **Bounding surfaces &**
 - **Layers of sediment****have the same age**

Link between time, surfaces & layers

- ⇒ **Application of Steno's principles and Walther's Law provide powerful and useful simplifications that assume the sediments packaged by surfaces accumulated within discrete moments of time.**
- ⇒ **If one thinks about this, these simplifications don't contravene logic (which is literally Fuzzy) and it aids in the interpretation of the sedimentary section.**

Bounding surfaces & their definition

Internal and external surfaces of any

⇒ Bed

⇒ Parasequence

⇒ Stratigraphic Sequence ←

Products of unique associations of processes.



Bounding surfaces & their definition

Sequence

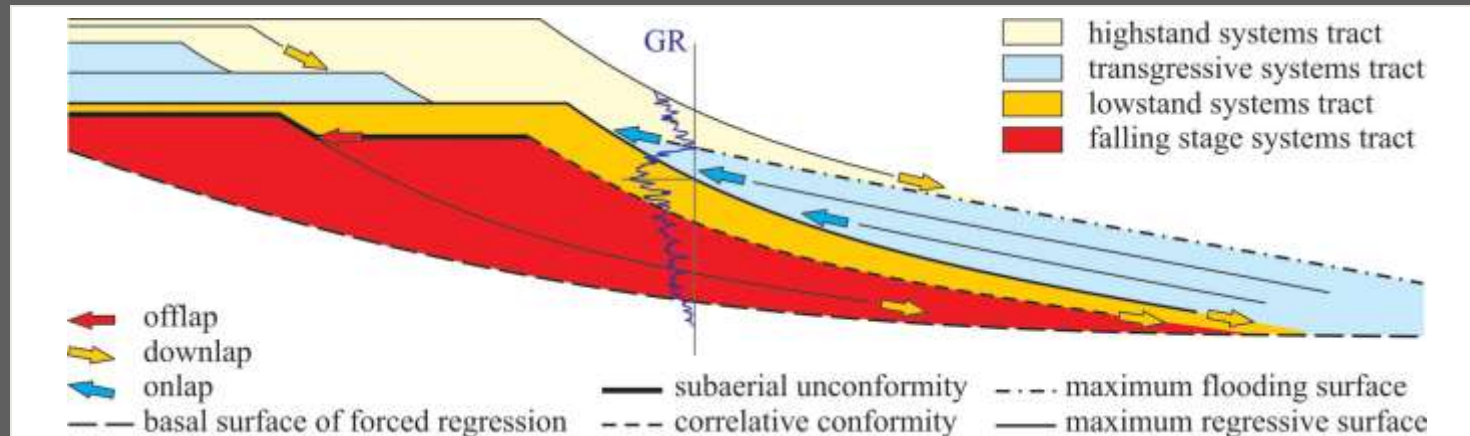
- ⇒ A relatively conformable succession of genetically related strata bounded at their upper surface and base by unconformities and their correlative conformities (*Vail, et al., 1977*)
- ⇒ Sequence is composed of a succession of genetically linked deposition systems (systems tracts) and is interpreted to be deposited between eustatic-fall inflection points (*Posamentier, et al., 1988*).
- ⇒ The sequences and the system tracts they enclose are subdivided and/or bounded by a variety of "key" surfaces that bound or envelope these discrete geometric bodies of sediment. They mark changes in depositional regime "thresholds" across that boundary.

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Bounding surfaces & their definition

Stratigraphic Sequence



A SEQUENCE & SYSTEMS TRACTS

*A Sea Level Cycle and the Responding
Sediment Geometry*

Movie Animation by C. G. St. C. Kendall. 2003

Sequence Stratigraphy – Basics
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Branches of stratigraphy

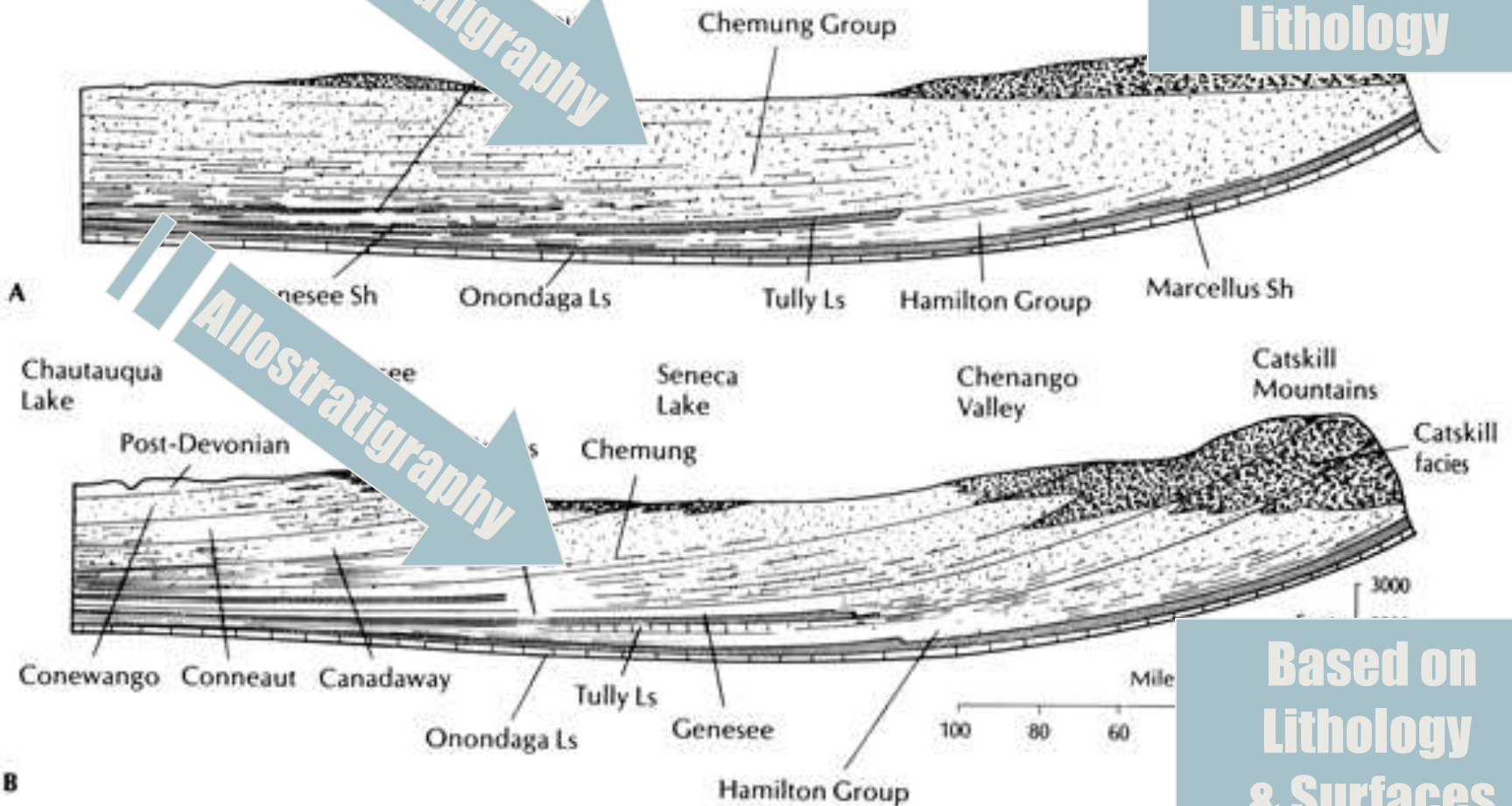
- ⇒ **Lithostratigraphy**: maps lithofacies independent of subdividing external & internal boundaries
- ⇒ **Allostratigraphy**: bounding discontinuities including erosion surfaces, marine flooding surfaces, tuffs, tempestite, and/or turbidite boundaries etc. as time markers
- ⇒ **Sequence Stratigraphy**: higher level allostratigraphic model which interprets depositional origin of sedimentary strata as products of "relative sea level change"



Lithostratigraphy & Allostratigraphy

Based on
Gross
Lithology

West

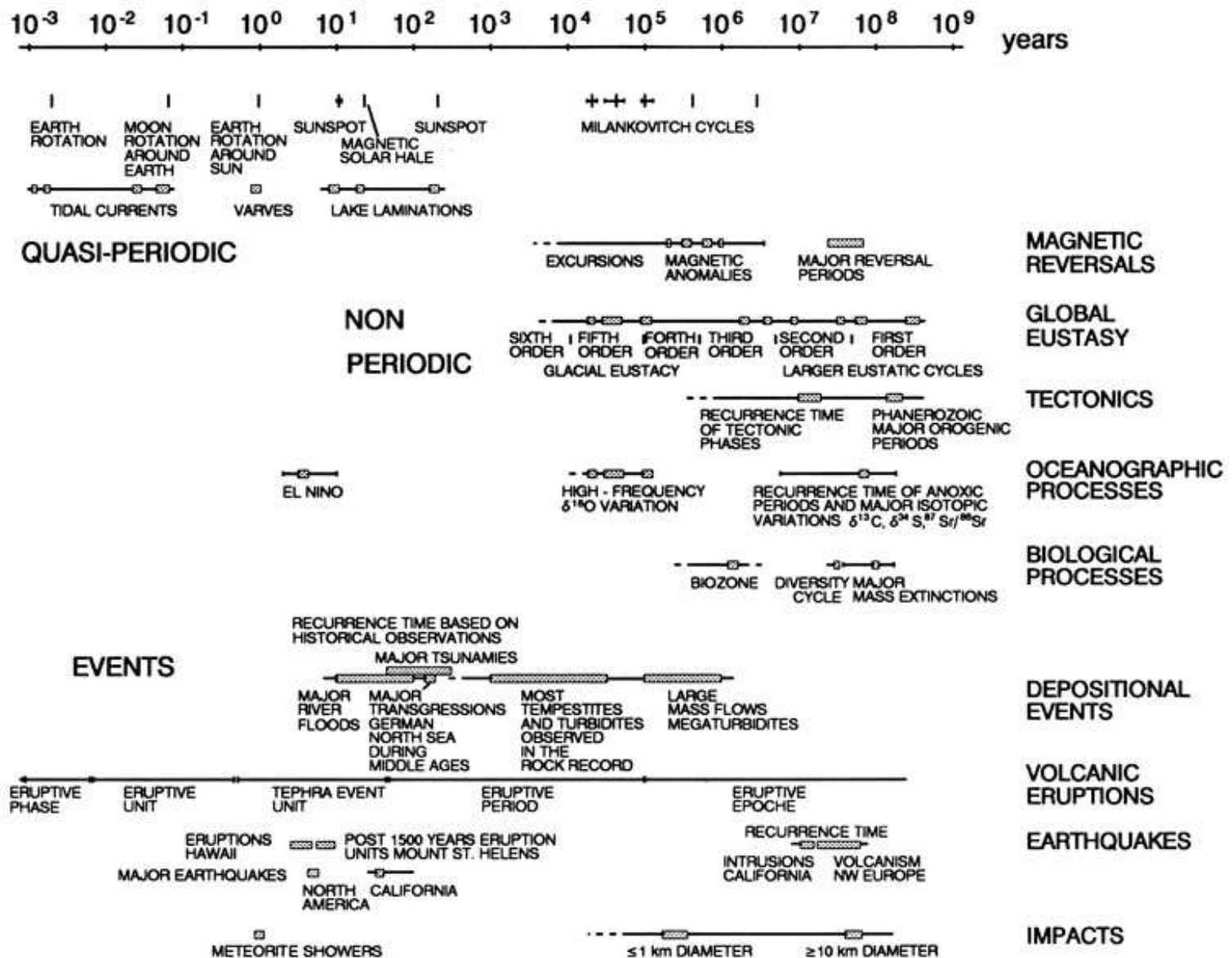


Based on
Lithology
& Surfaces

Branches of stratigraphy

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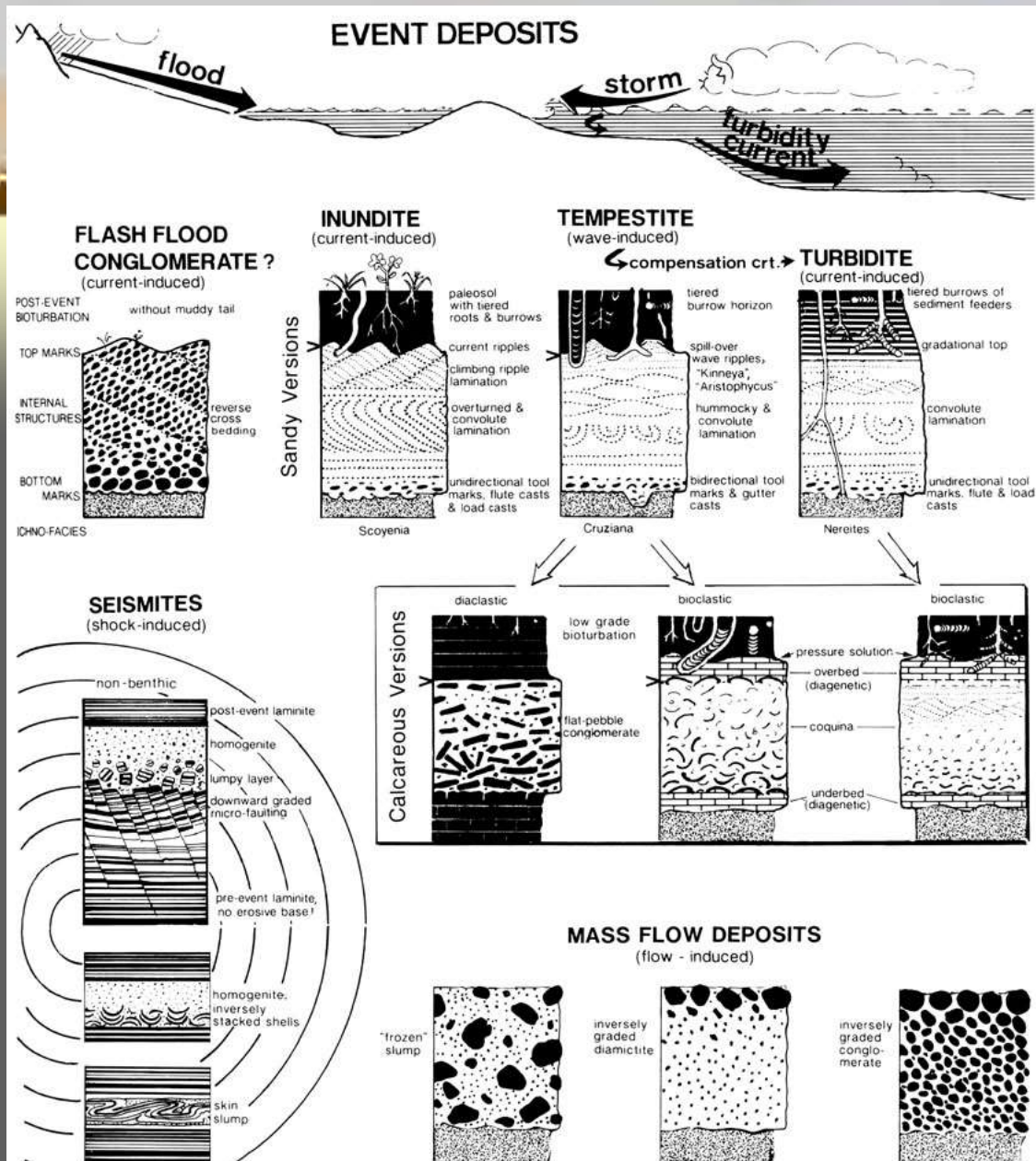
Major recurrence time of quasi-periodic and nonperiodic processes as well as events.

Branches of stratigraphy

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Allostratigraphic Events & Surfaces



Basic pattern of event deposits (SEILACHER, 1991)

Branches of stratigraphy

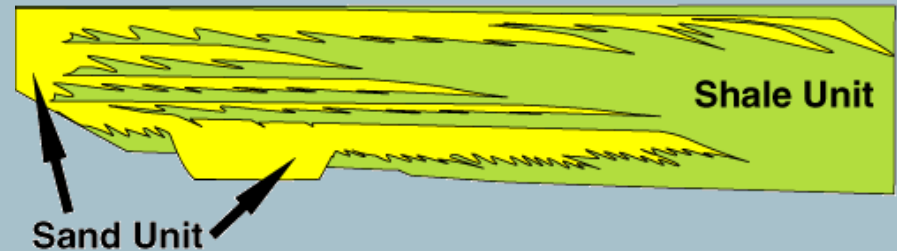
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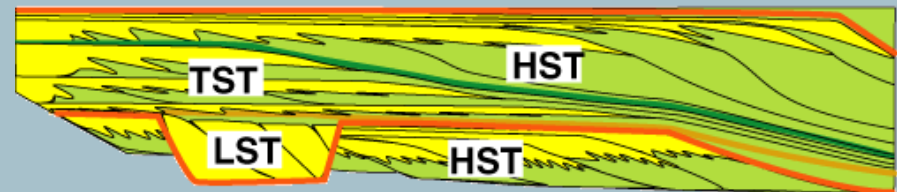
Lithostratigraphy & Allostratigraphy

Sequence Stratigraphic
Higher level
allostratigraphic model
that enables
interpretation of
sedimentary strata as
products of "relative sea
level change"

*Correlations based on Lithology
- Lithostratigraphic*



*Correlations based on Bounding
Surfaces - Allostratigraphic*



Key

- mfs (Maximum Flooding surface)
- TS (Transgressive Surface)
- SB (Sequence Boundary)
- LST Lowstand System Tract
- TST Transgressive System Tract
- HST Highstand System Tract

Lithostratigraphy & Allostratigraphy

A SEQUENCE & SYSTEMS TRACTS *A Sea Level Cycle and the Responding Sediment Geometry*

Movie Animation by C. G. St. C. Kendall. 2003

Sequence Stratigraphy

Higher level allostratigraphic model that interprets sedimentary strata in terms of bounding surfaces that are the products of "relative sea level change"

Bounding Surfaces

Subdivide sedimentary rock. Best understood by iteratively applying conceptual models that link processes that formed them.

Provide:-

- ⇒ Relative time framework to sedimentary succession**
- ⇒ Better understanding inter-relationship of depositional settings & their lateral correlation**



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Sequence Stratigraphy

- ➔ Study of rock relationships within a time-stratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition, or their correlative conformities (Posamentier et al., 1988; Van Wagoner et al., 1988).
- ➔ Implicit but sometimes unstated connection between the external and internal surfaces of a sequence and base level change.



Sequence Stratigraphic Surfaces

- ⇒ Sequence stratigraphy is based on the application of the systematic subdivision of the section by well defined surfaces
- ⇒ These surfaces are used to provide a framework to the interpretation of the depositional settings of the sedimentary section
- ⇒ This interpretation is then used to predict the extent and character of the component sedimentary facies



Sequence Boundary (SB)

- ⇒ Envelope Sequence
- ⇒ Significant erosional unconformity & correlative disconformity formed by drop in base level (sea level?)
- ⇒ Erodes subaerially exposed sediment surface of earlier sequence or sequences
- ⇒ Diachronous boundary between underlying Highstand System Tract (HST) & overlying Falling Stage System Tract (FSST) or Early Lowstand System Tract (ELST)
- ⇒ Erode surface of downstepping sediments deposited during accompanying forced regression associated with sea level fall



Sequence Boundary (SB)

FALLING STAGE SYSTEMS TRACT

*Falling Sea Level & High Sedimentation Cause
Forced Regression & Prograding Clinoforms
Enveloped by Sequence Boundary
& Transgressive Surface*

Movie Animation by C. G. St. C. Kendall. 2003



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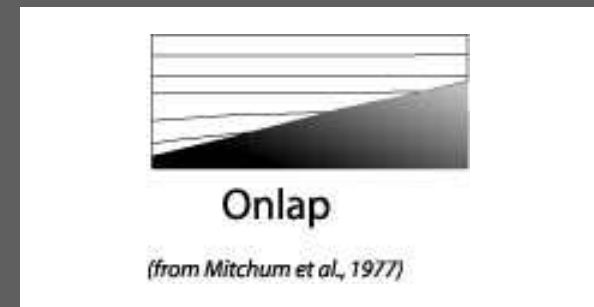
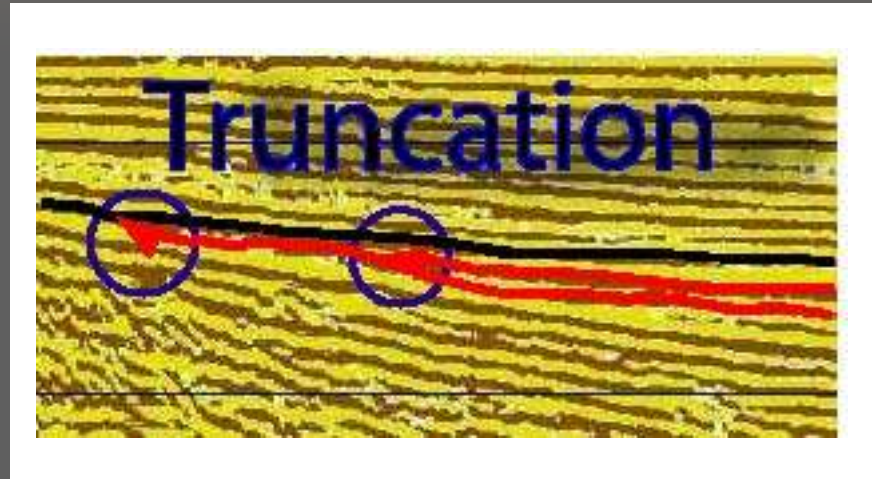
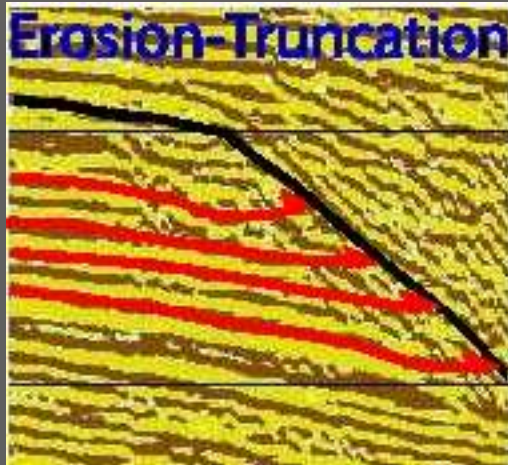


Characteristics of Sequence Boundary (SB) from seismic

- ⇒ Defined by erosion or truncation of underlying reflectors or the correlative conformity
- ⇒ Can be inferred from onlapping reflectors overlying a surface
- ⇒ Should the upper surface of a falling stage system tract be eroded when a shoreline is forced seaward (a forced regression!) by a drop in sea level (or base level) the interpretation of a sequence boundary is ambiguous

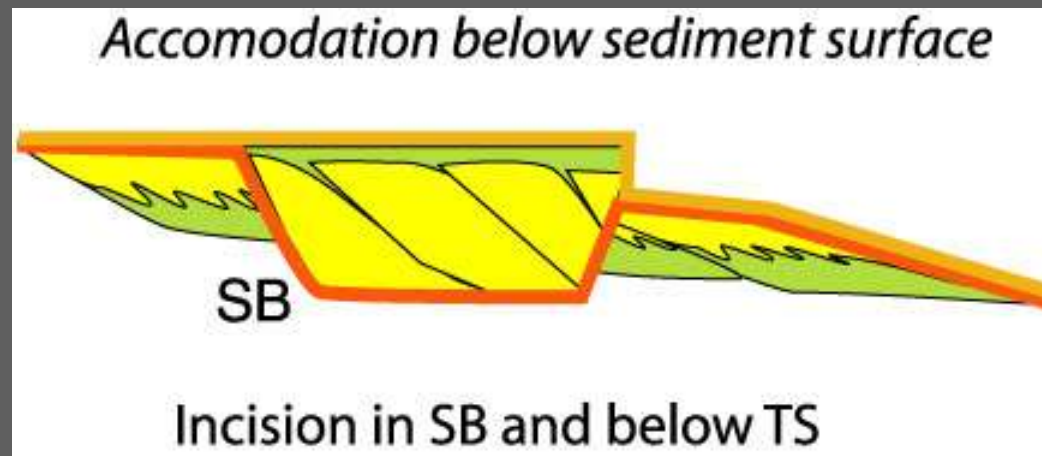


Characteristics of Sequence Boundary (SB) from seismic



Characteristics of Sequence Boundary (SB) from well logs, core & outcrop

- ⇒ Defined by erosion or incision of underlying flooding surfaces (mfs and TS)
- ⇒ Inferred from interruption in the lateral continuity of these surfaces

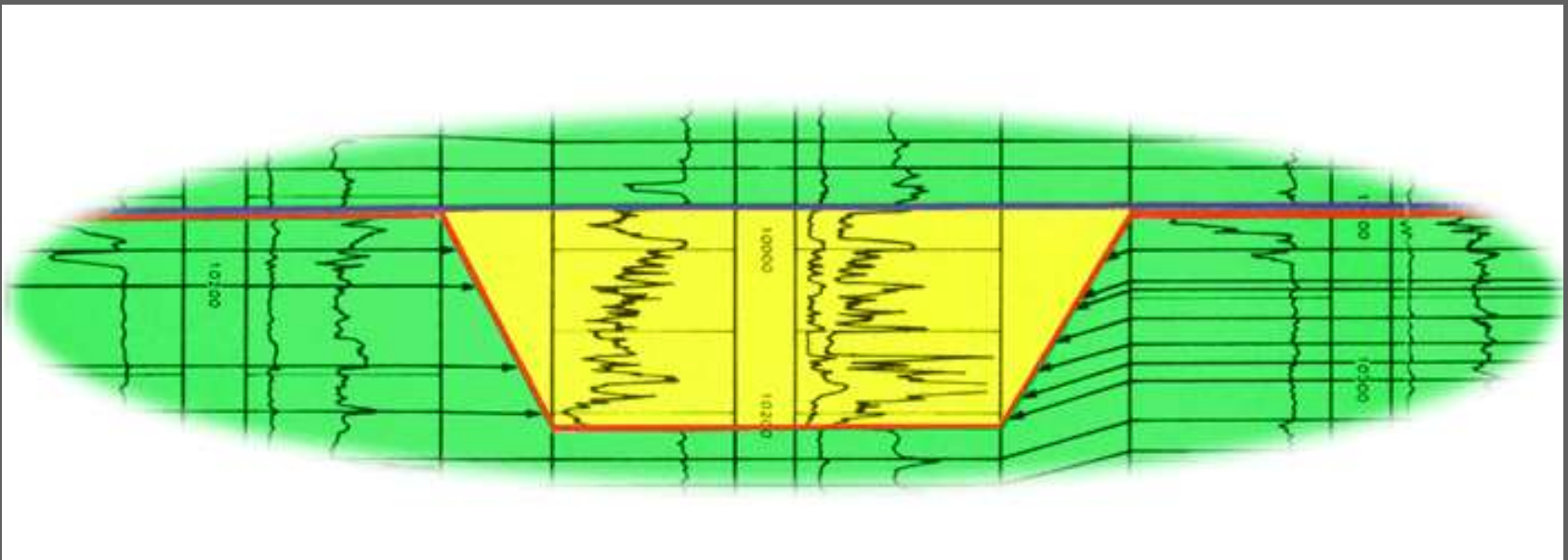


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Characteristics of Sequence Boundary (SB) from well logs, core & outcrop

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- ⇒ Inferred from interruption in the lateral continuity of these surfaces



Transgressive Surface (TS)

- ⇒ **Product of rise in base level (sea level?)**
- ⇒ **Lies at boundary between underlying Late Lowstand System Tract (LLST) and the overlying Transgressive system tract (TST)**
- ⇒ **Marine-flooding surface that forms first significant flooding surface in a sequence - often marking base of most prominent onlap.**
- ⇒ **Formed when rate of creation of accommodation space is greater than the rate of sediment supply.**
- ⇒ **In rimmed carbonate platforms, the rate of sediment supply may keep pace with the rate of relative sea-level rise and thus TS marks change from a progradational to an aggradational parasequence stacking patterns.**

Transgressive Surface (TS)

TRANSGRESSIVE SYSTEMS TRACT
Rapid Sea Level Rise & Low Sedimentation
Produce Retrogradational Onlapping
Parasequences Enveloped by Transgressive
Surface and Maximum Flooding Surface (mfs)

Movie Animation by C. G. St. C. Kendall. 2003



"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



Characteristics of Transgressive Surface [TS] from seismic

- ⇒ Defined by onlapping reflectors over and onto a surface (SB)



Characteristics of Transgressive Surface [TS] - well logs, core & outcrop

- ⇒ Defined by erosion or incision of underlying onlapped sediment (Ravinement)
- ⇒ Inferred from presence of Glossifungites in this surface
- ⇒ Inferred from presence of nick or neck on resistivity logs caused by presence of carbonate cements probably derived from the carbonate fauna eroded during the Ravinement



Characteristics of Transgressive Surface [TS] - well logs, core & outcrop

⇒ Defined by erosion or incision of underlying onlapped sediment (Ravinement)

TRANSGRESSIVE SYSTEMS TRACT
*Rapid Sea Level Rise & Low Sedimentation
Produce Retrogradational Onlapping
Parasequences Enveloped by Transgressive
Surface and Maximum Flooding Surface (mfs)*

Movie Animation by C. G. St. C. Kendall. 2003

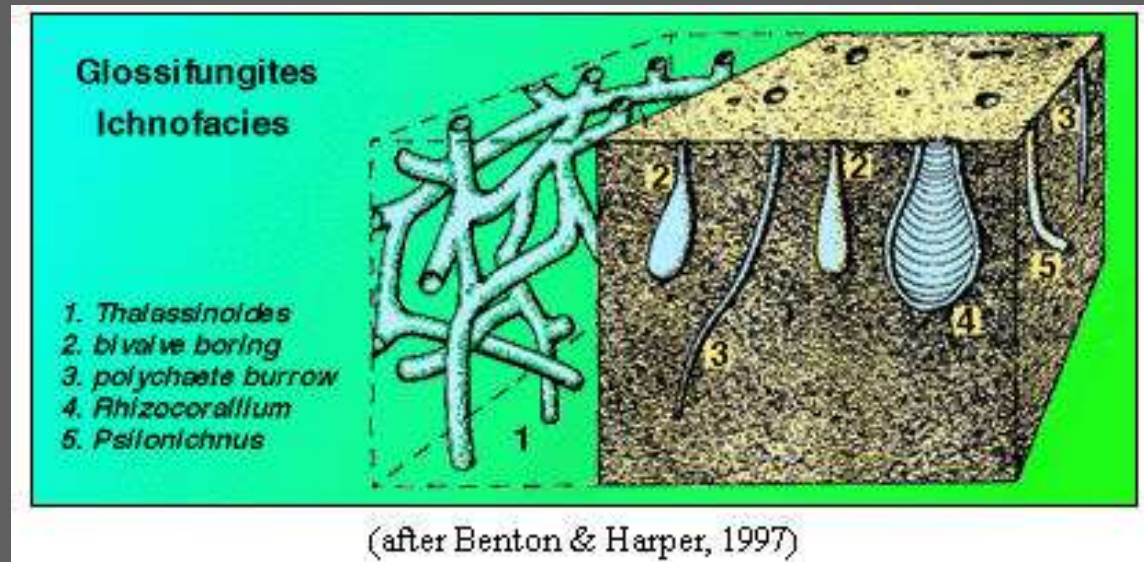


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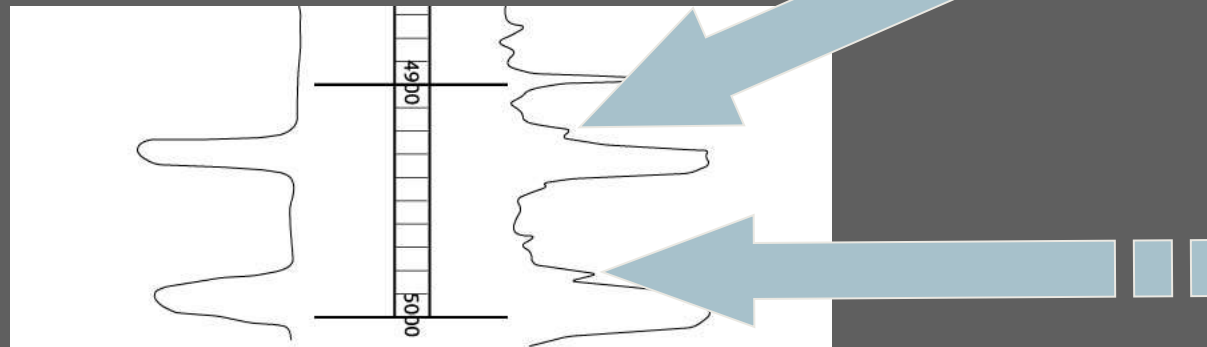
Characteristics of Transgressive Surface [TS] - well logs, core & outcrop

⇒ Inferred from presence of Glossifungites in this surface)



Characteristics of Transgressive Surface [TS] - well logs, core & outcrop

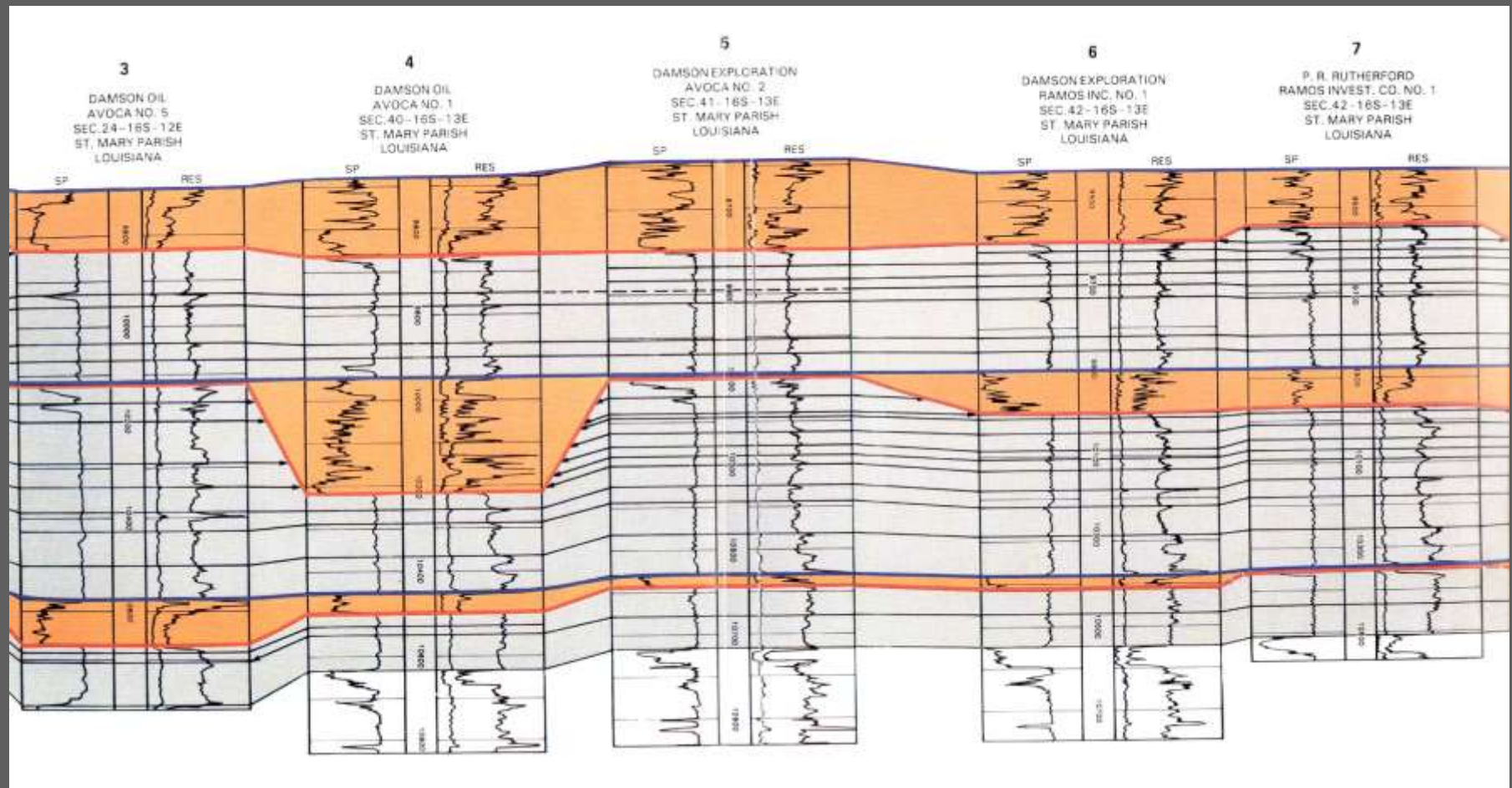
- ⇒ Inferred from presence of nick or neck on resistivity logs caused by presence of carbonate cements probably derived from the carbonate fauna eroded during the Ravinement



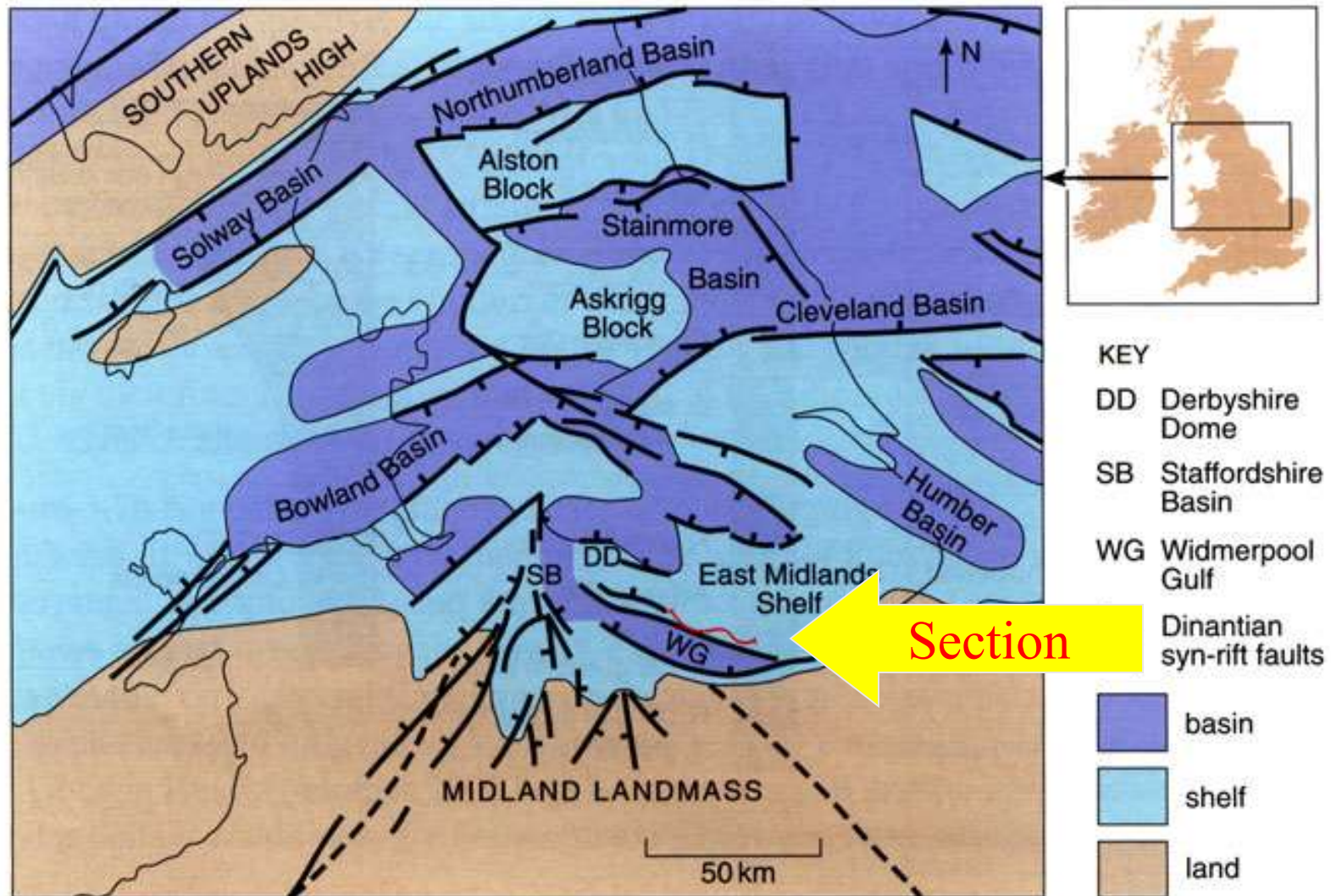
"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



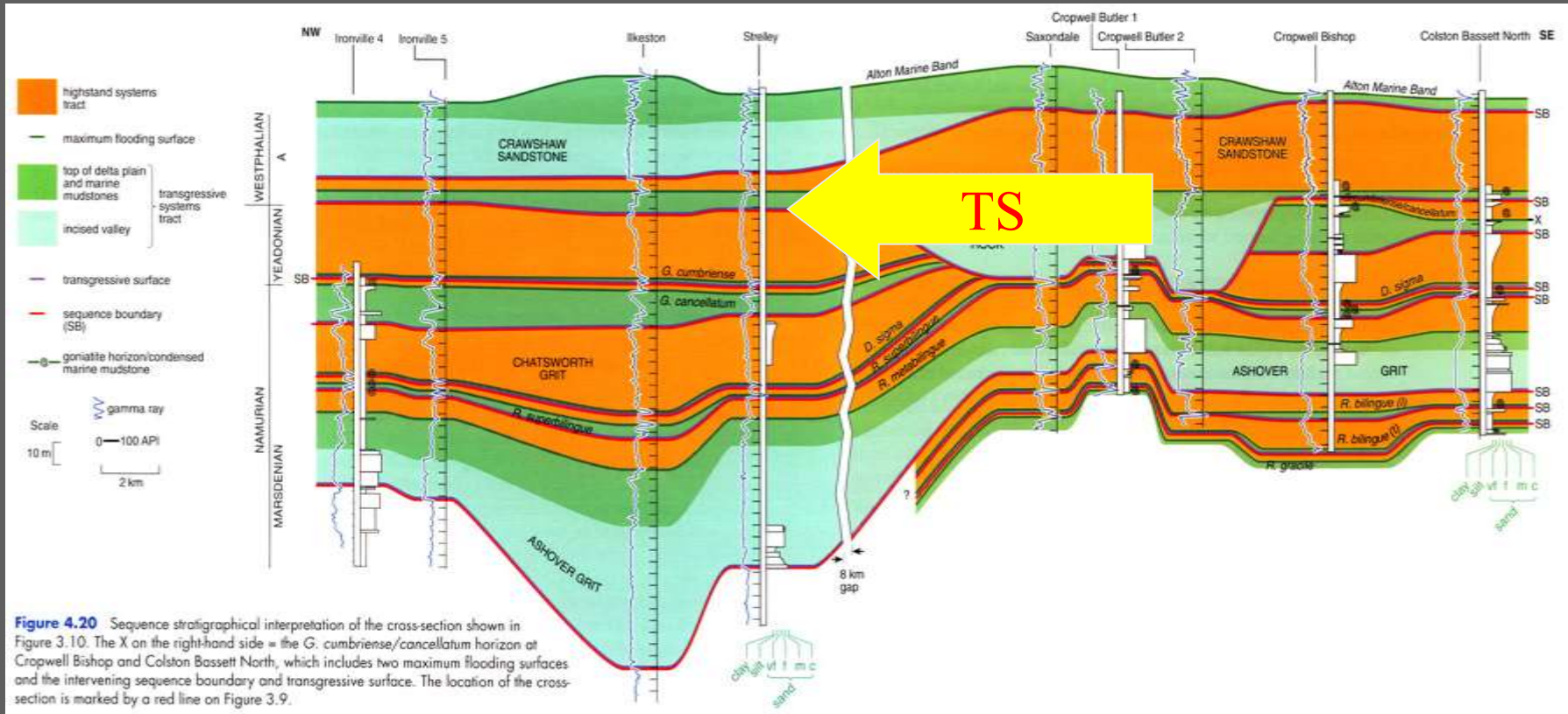
Characteristics of Transgressive Surface (TS) - well logs, core & outcrop



Transgressive Surface [TS] - well logs, core & outcrop



Transgressive Surface [TS] - well logs, core & outcrop



Maximum Flooding Surface (mfs)

- ⇒ **Product of maximum flooding or transgression of shelf or stillstand in base level (sea level?)**
- ⇒ **Lies at the boundary between the underlying Transgressive system tract (TST) and the overlying High stand system tract (HST)**
- ⇒ **Often expressed as a downlap surface.**
- ⇒ **Marine shelf and basinal sediments associated with this surface product of slow rates of deposition of pelagic-hemipelagic sediments**
- ⇒ **Make up condensed section and are usually thin**

Maximum Flooding Surface (mfs)

HIGHSTAND SYSTEMS TRACT

Sea Level Still Stand & Low Sedimentation

Produce Prograding Onlapping

Clinofolds Enveloped by Maximum Flooding Surface (mfs) & Upper Sequence Boundary

Movie Animation by C. G. St. C. Kendall. 2003



"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



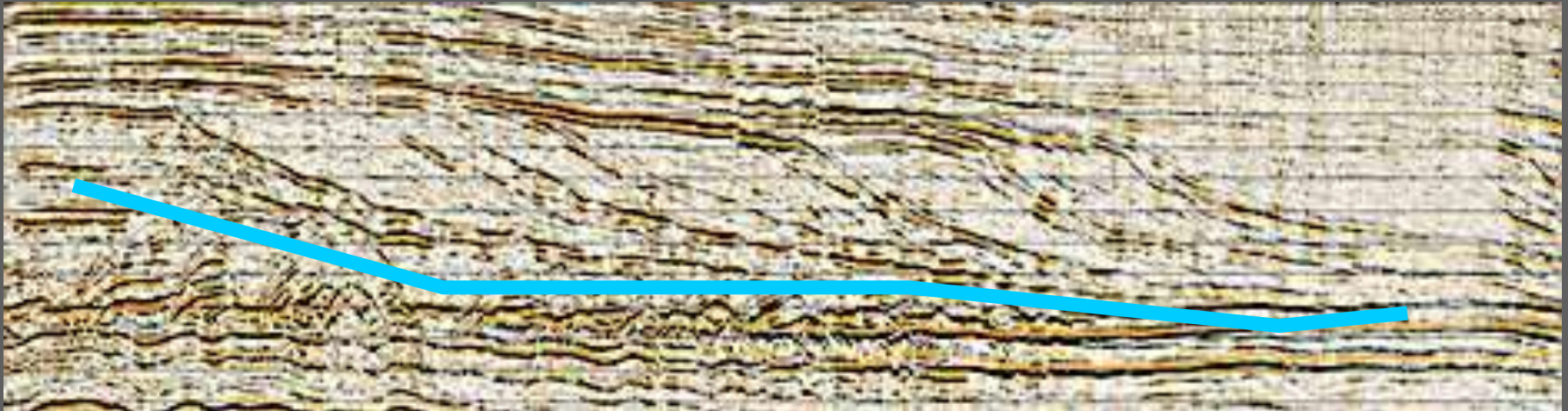
Characteristics of Maximum Flooding Surface (mfs) from seismic

⇒ Often expressed as a downlap surface.



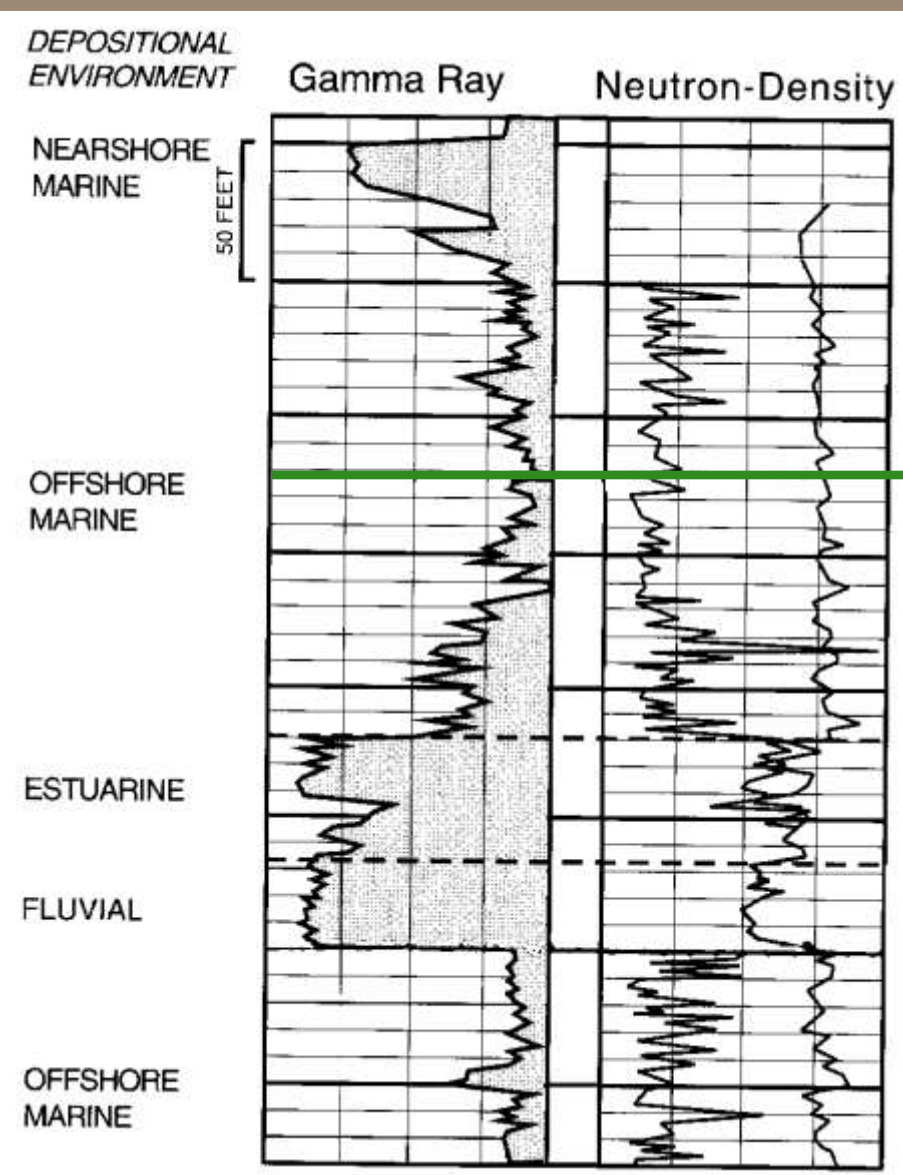
Characteristics of Maximum Flooding Surface (mfs) from seismic

- ⇒ Defined as lying immediately below the downlapping reflectors prograding reflectors of the HST



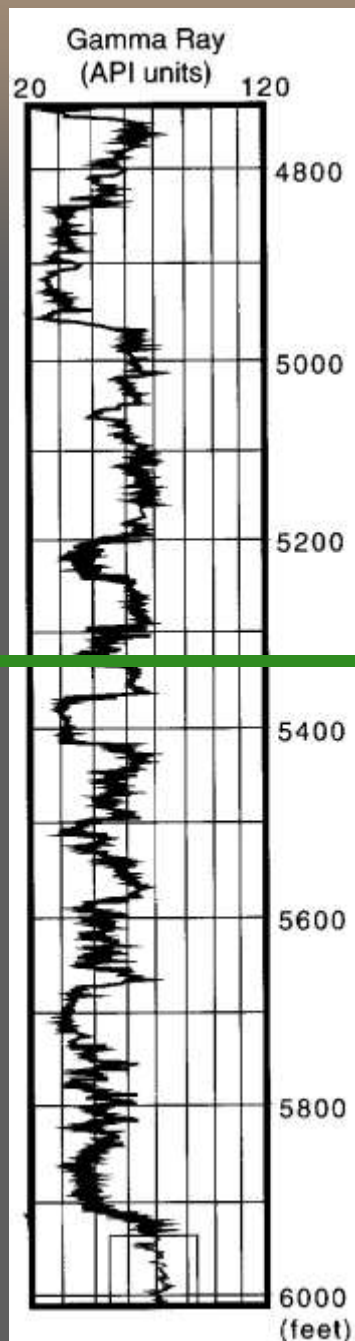
Characteristics of Maximum Flooding Surface (mfs) from well logs, cores, & outcrop

- ⇒ **Defined by organic often radioactive (big kicks on gamma ray logs) black shales**
- ⇒ **Not infrequently overlain by coarser sediments (often sand sized)**
- ⇒ **Inferred from presence of condensed faunal association**
- ⇒ **Inferred from presence of finest grain size**



**Maximum
Flooding
Surface
[mfs]
well logs,
core & outcrop**

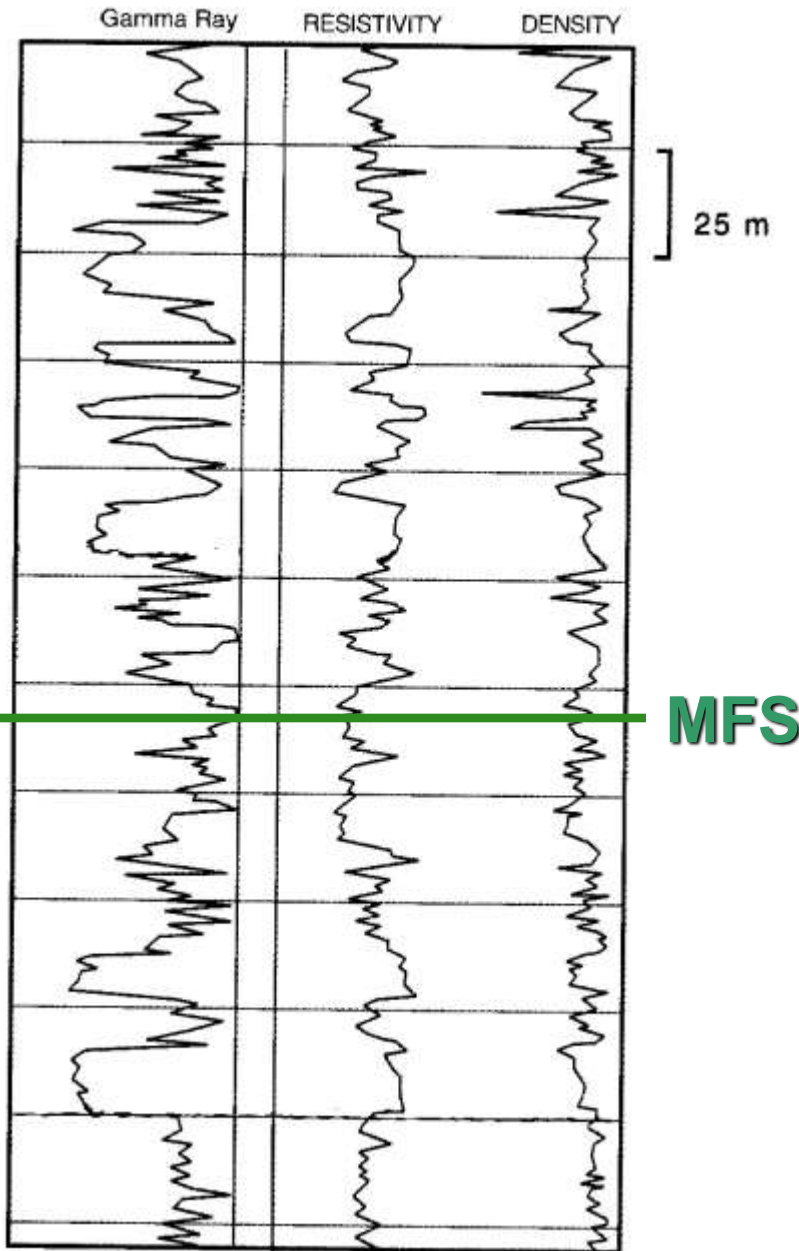
After Hanford



Maximum Flooding Surface (mfs) well logs, core & outcrop

MFS

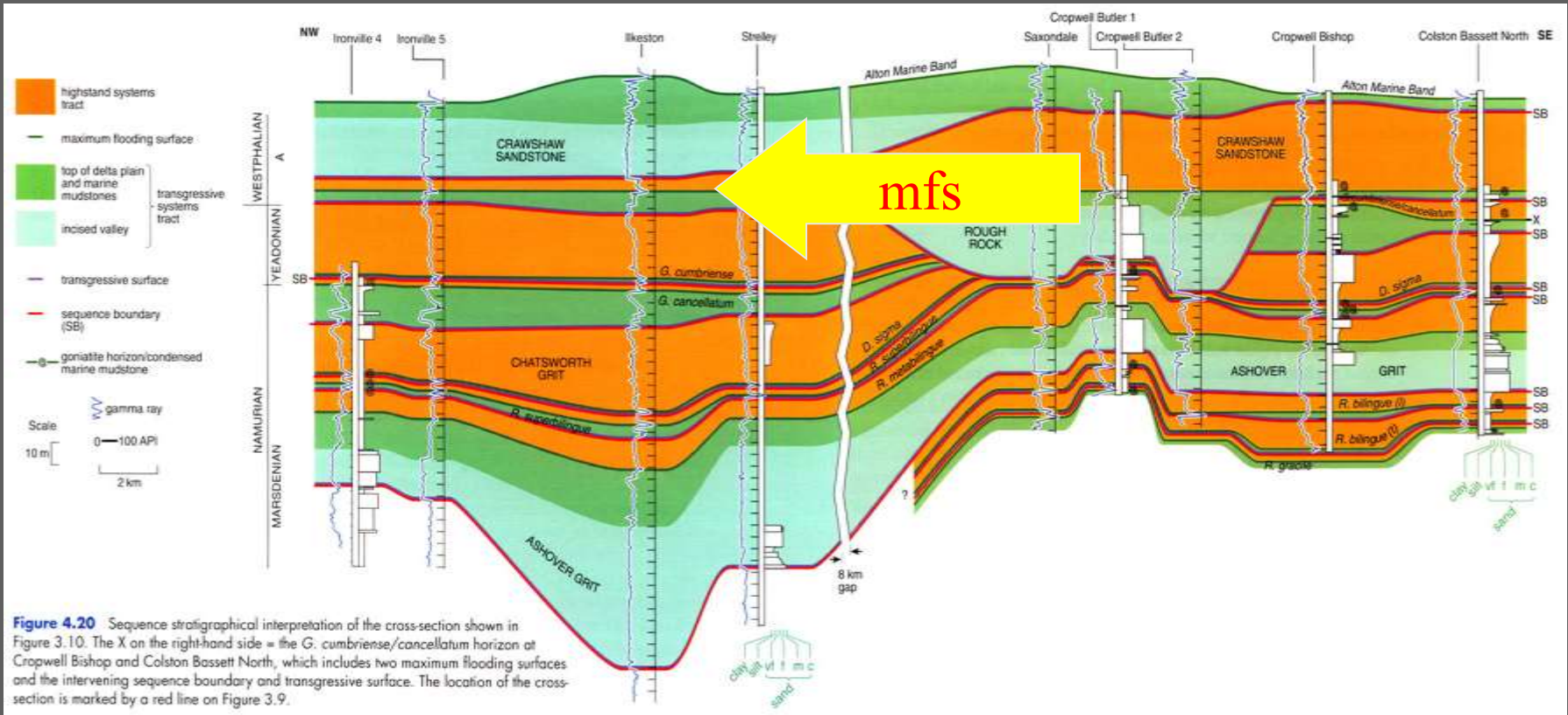
After Hanford



**Maximum
Flooding
Surface
[mfs]
well logs,
core &
outcrop**

After Hanford

Maximum Flooding Surface [mfs] - well logs, core & outcrop



After Coe et al

Maximum Flooding Surface (mfs)

- ⇒ **Product of maximum flooding or transgression of shelf or stillstand in base level (sea level?)**
- ⇒ **Lies at boundary between underlying Transgressive system tract (TST) and overlying High stand system tract (HST)**
- ⇒ **Often expressed as a downlap surface.**
- ⇒ **Marine shelf and basinal sediments associated with this surface product of slow rates of deposition of pelagic-hemipelagic sediments**
- ⇒ **Often associated with condensed sections, high gamma ray signals and are usually thin**

Definitions

sediment: unconsolidated* material that is produced on Earth's surface by the disaggregation of pre-existing rocks

sedimentary rock: a consolidated body formed from sediments or ***solutes*** that are transported and deposited by gravity, biologic activity, or a ***fluid*** and then ***lithified*** by the combined effects of ***compaction*** and ***cementation***

sedimentology: the study of the ***production, transport, and deposition*** of sediment

* some exceptions apply

"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



Definitions

strata: layers of (usually sedimentary) rock

stratigraphy:

1. the description, study, and/or application of the composition of layered (usually sedimentary) rocks
2. a **succession** of layered rocks; *e.g.*, the stratigraphy of South Carolina

basin:

1. a region of potential sediment **accumulation** generally caused by **subsidence**
2. the largest possible body of related and once-contiguous* strata; *e.g.*, the Appalachian basin

* some exceptions apply

"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



Definitions

faciere: to send, to put, to place, *to make*
→ **facies**: outward appearance, sight, form, shape

facies: the face; the general aspect of any group of organisms or of rocks (*Webster's 1945*)

facies: a rock distinguished from others by its appearance or composition (*www.dictionary.com*)



Definitions

strata: layers of (usually sedimentary) rock

stratigraphy:

1. the description, study, and/or application of the composition of layered (usually sedimentary) rocks
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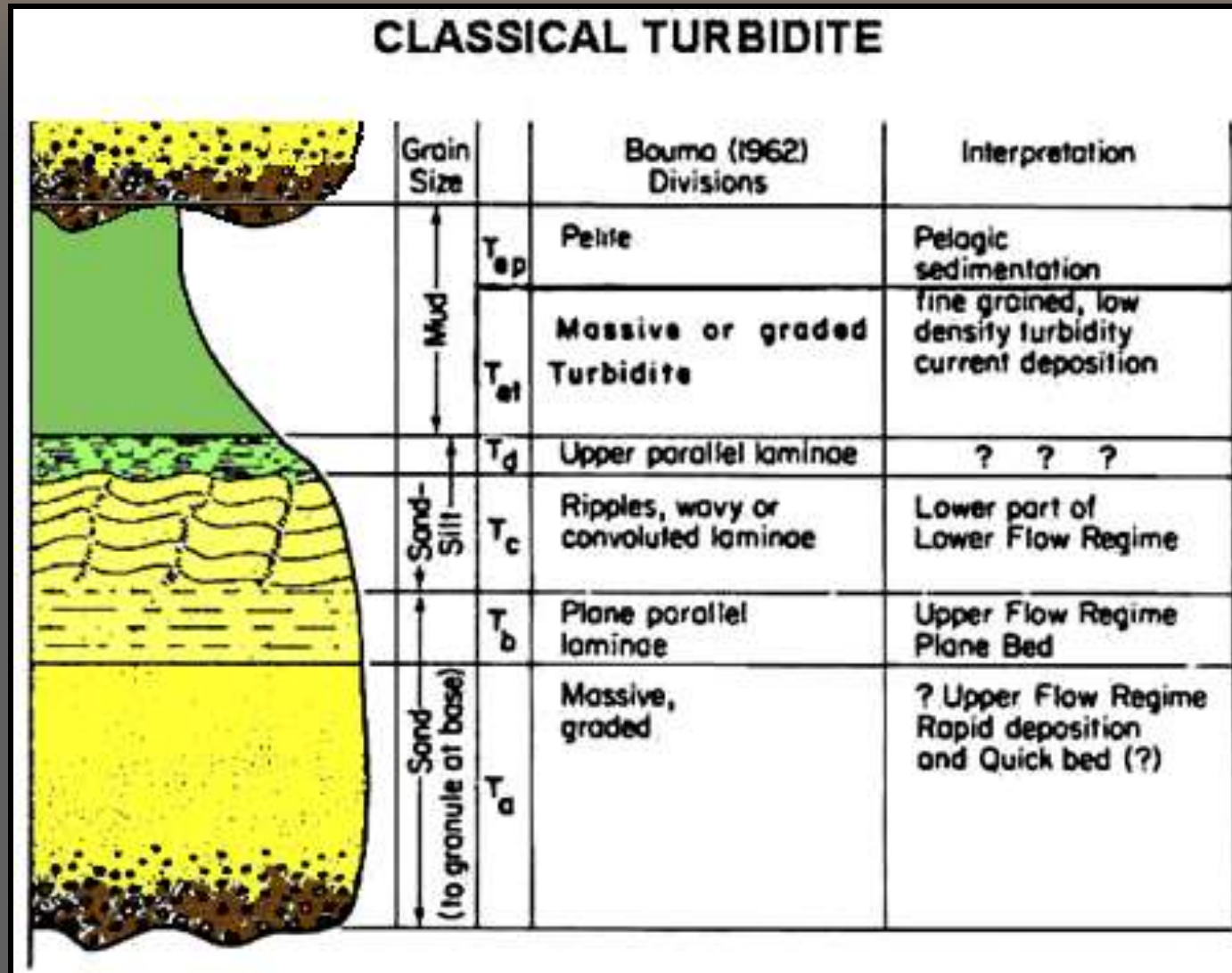
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* some exceptions apply

"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



Sedimentary Facies



C. G. St. C. Kendall



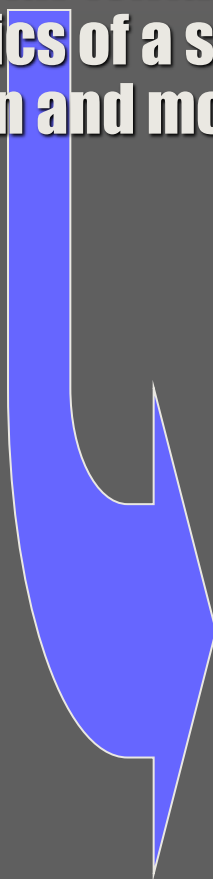
Sedimentary Facies

- ⇒ **facies**: the total textural, compositional and structural characteristics of a sedimentary deposit resulting from accumulation and modification in a particular environment.



Sedimentary Facies

⇒ ***facies***: the total textural, compositional and structural characteristics of a sedimentary deposit resulting from accumulation and modification in a particular environment.

- 
- grain size, sorting, rounding
 - lithology
 - sedimentary structures
 - bedding type



Sedimentary Facies

- ⇒ ***facies***: the total textural, compositional and structural characteristics of a sedimentary deposit resulting from accumulation and modification in a particular environment.
- ⇒ ***EX: well-sorted, moderately rounded, trough cross-stratified, horizontally burrowed & normally graded arkosic coarse sandstone***



Lithofacies & Lithofacies Codes

- ⇒ Sedimentary facies often get reduced to ***lithofacies*** which detail grain-size, composition, and dominant sedimentary structures only
 - EX: planar cross-stratified gravel, inversely graded massive sandstone
- ⇒ This has led to lithofacies codes (after Miall, 1978).
 - EX: Gmm, St, Fsl

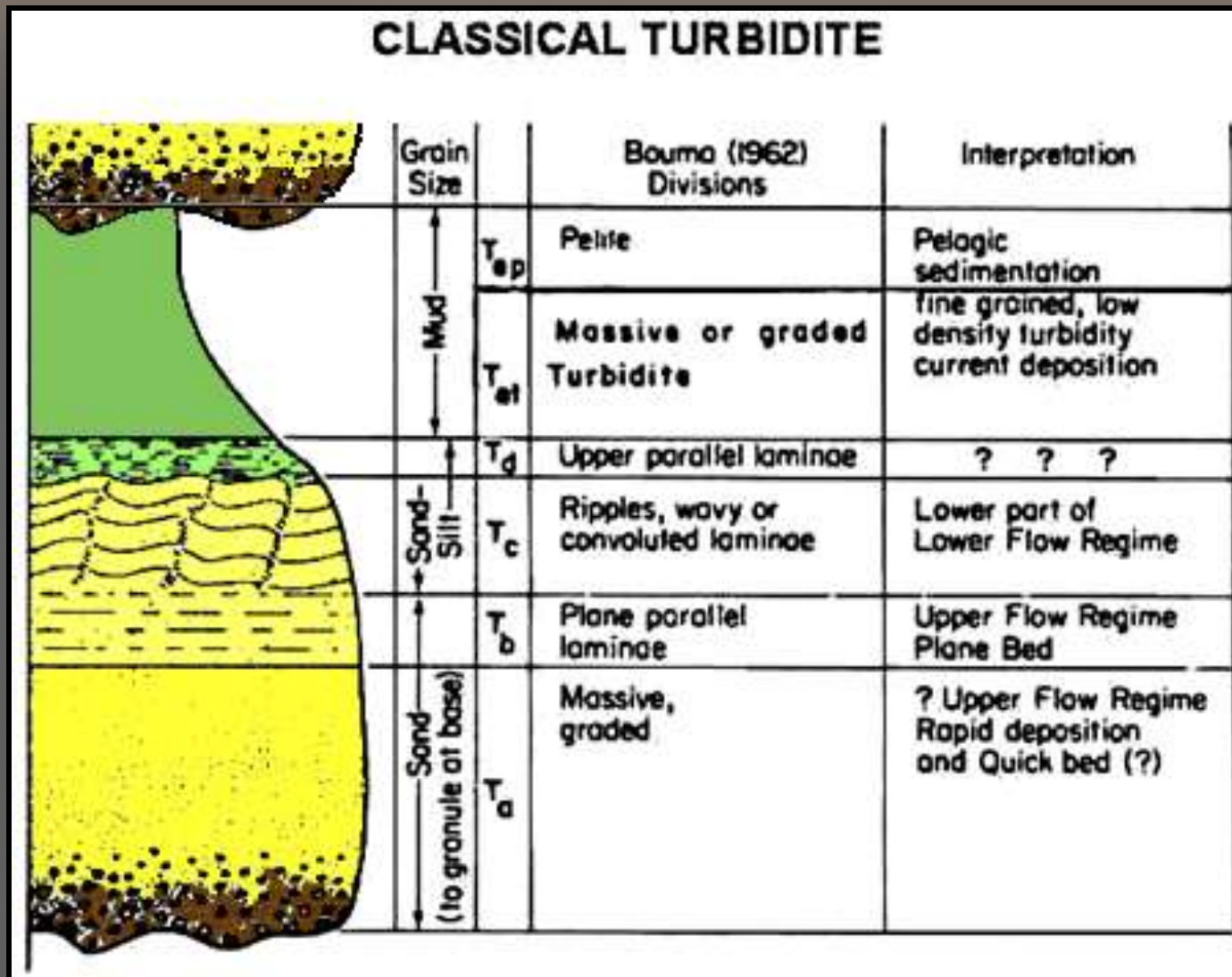


Sedimentary Facies

- ⇒ **facies**: the total textural, compositional and structural characteristics of a sedimentary deposit resulting from accumulation and modification in a particular environment.
- ⇒ **facies assemblage**: collection of multiple facies resulting from genetically related accumulation and modification.
- ⇒ **EX: lenticularly bedded stratified pebble conglomerate with subordinate planar cross-stratified sandstone**
- ⇒ **OR: fluvial channel lithofacies assemblage**



Facies Assemblage



Depositional Systems

- ⇒ **depositional system**: assemblage of multiple process-related sedimentary facies assemblages, commonly identified by the geography in which deposition occurs.
 - EX: nearshore depositional system, deep marine depositional system, glacial depositional system, fluvial depositional system

- ⇒ **NB depositional systems are:**
 - modern features
 - used to interpret ancient sedimentary successions



Sequence stratigraphic analysis

This analysis involves

- ⇒ **Subdivision of section into sequences, parasequences and beds.**
- ⇒ **Link conceptual models with mix of components of the individual sequence, parasequence or beds**
- ⇒ **Use these to explain the depositional setting in terms of their lithology, grain size, sedimentary structures, contacts character (gradational, abrupt) etc**



"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall



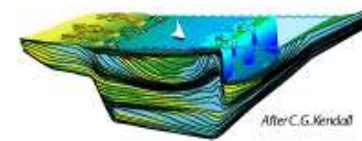
Sequence Stratigraphic Analysis

Creation of stratigraphic cross sections & geologic models of carbonates

The use of sequence stratigraphy to correlate & interpret carbonates from well logs & cores

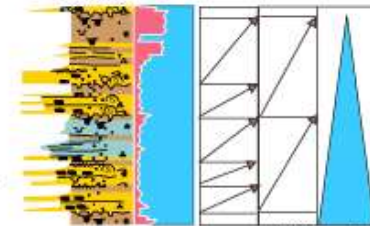
Depositional setting of the carbonates determined from:

Geological model provided by literature



After C.G. Kendall

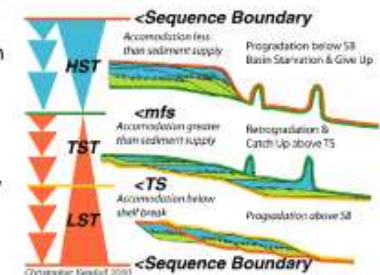
Graphic column that characterizes lithology
grain size
sedimentary structures
fossils
surfaces subdividing parasequences



After C.R. Handford

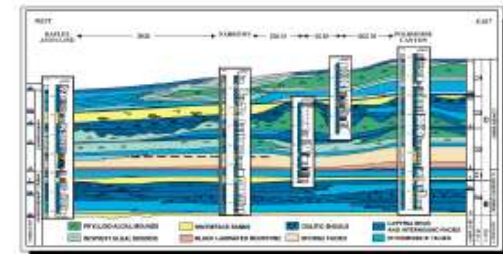
Subdivision by these surface into parasequence stacking patterns reflecting

Grain size
Thickness
Facies architecture & trajectory caused by changes in rates of change of sea level, sediment accumulation, and sea floor slope affecting:
Sequence boundaries (SB)
Flooding surfaces (TS & mfs)
& determining direction of shoreline motion; namely
Progradation
Aggradation
Retrogradation



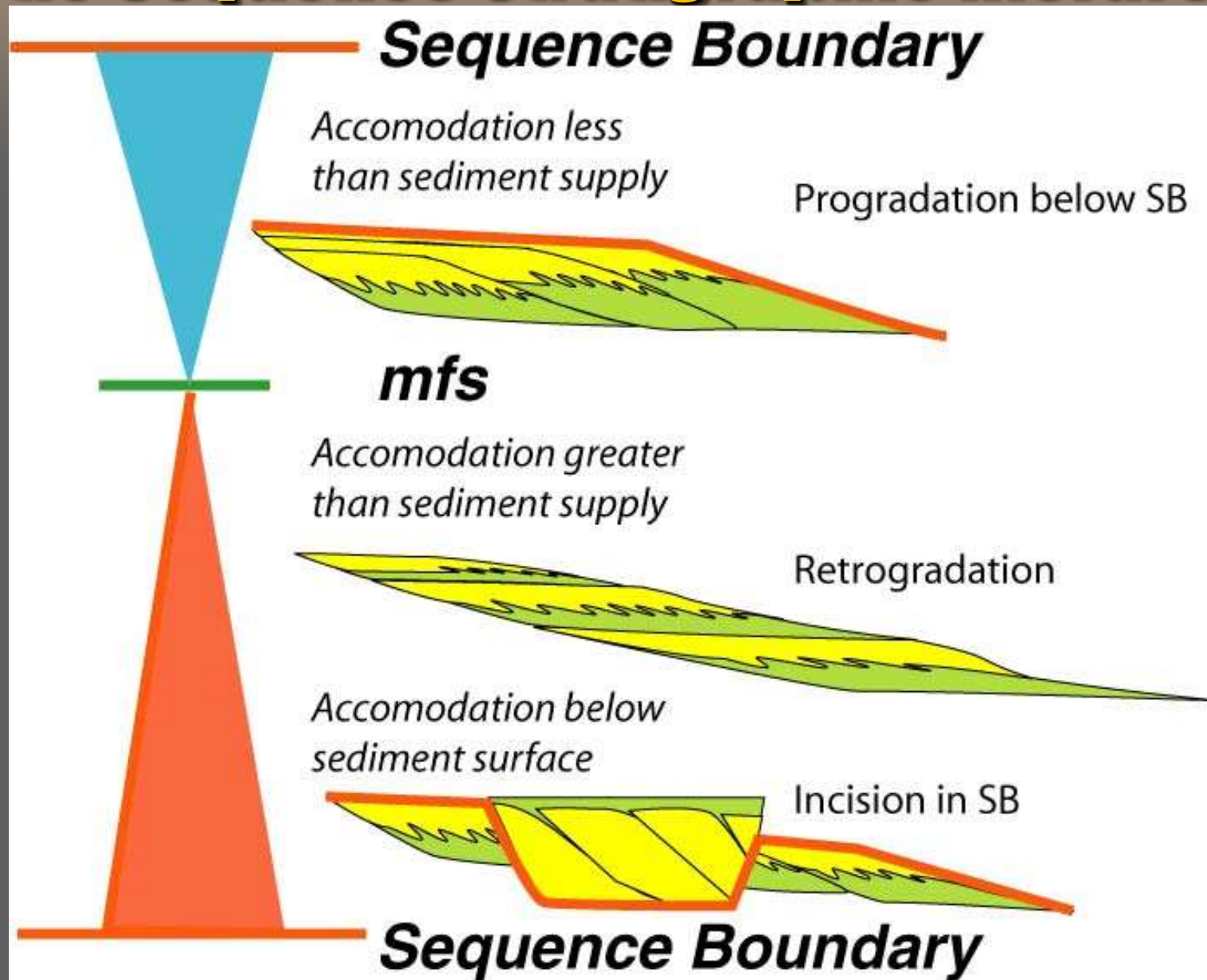
Christopher Kendall 2000

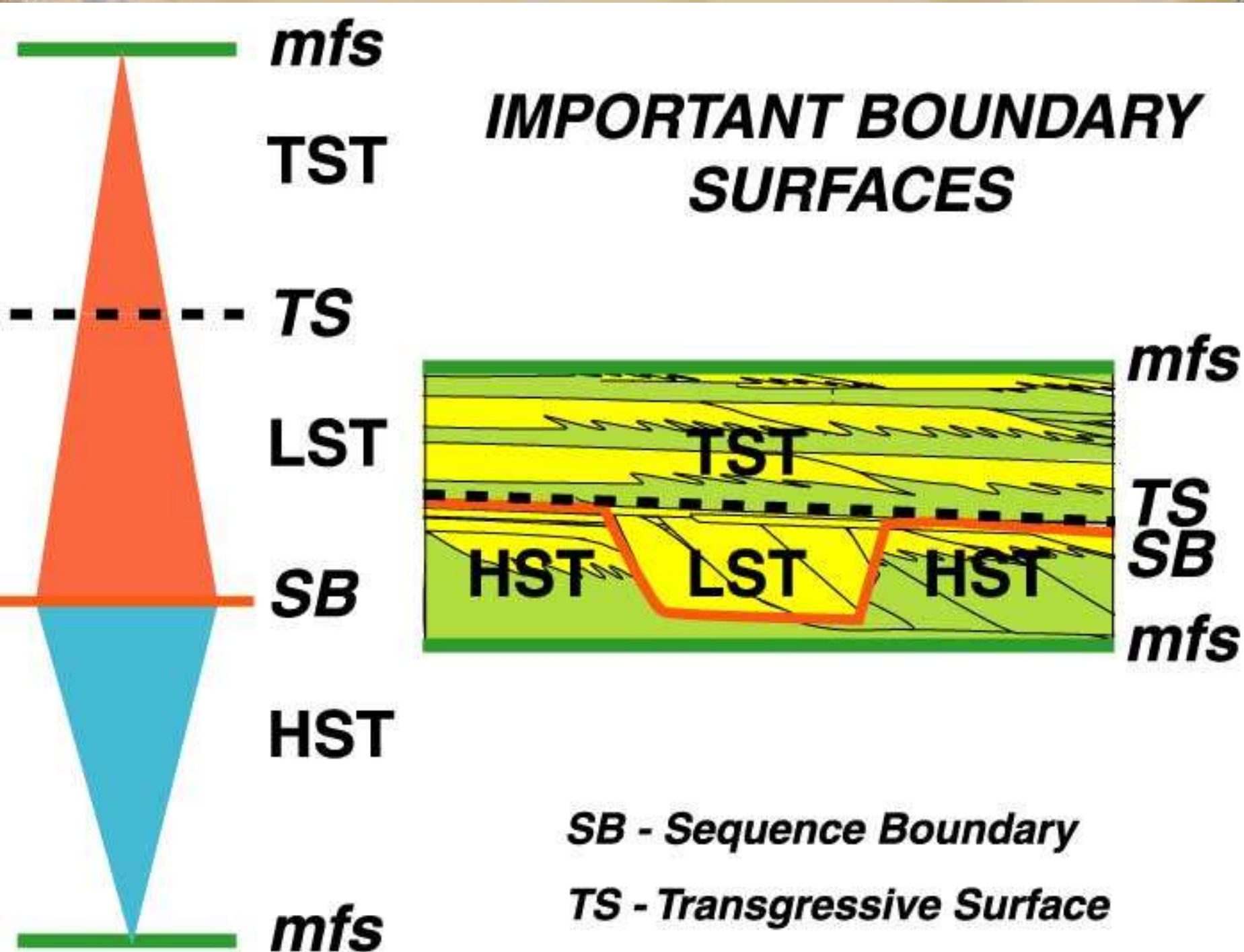
Creation of stratigraphic cross sections & geologic models of carbonates



After Eberli et al 2001

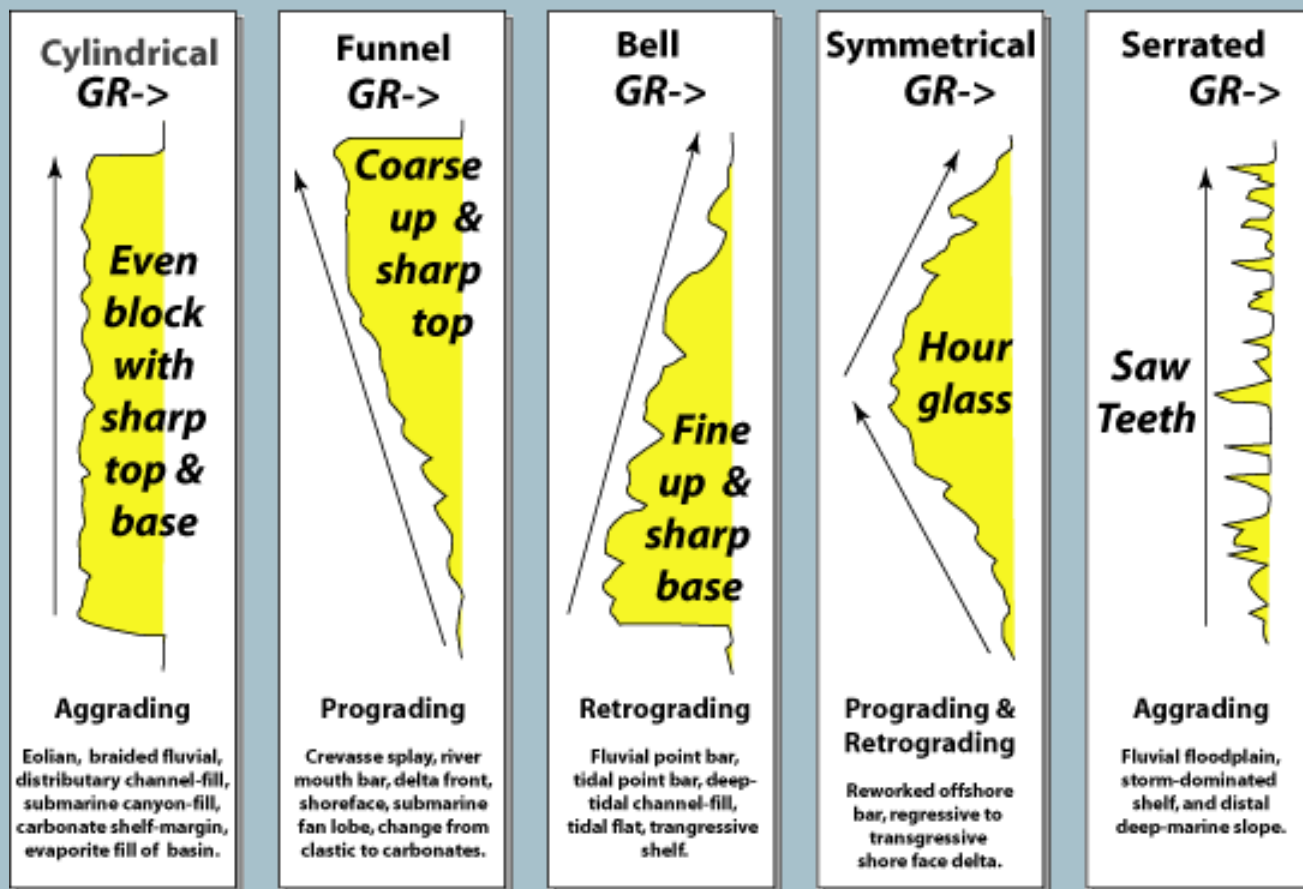
Clastic Sequence Stratigraphic Hierarchies





Clastic Sequence Stratigraphic Hierarchies

General Gamma Ray Response to Variations in Grain Size



C. G. St. C. Kendall (2003) modified from Emery (1996)

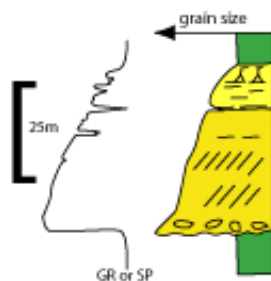
CLASTIC SEQUENCE HIERARCHY

- ⇒ **SHELF & MARGIN COMPLEX** – Mix of shelf, coastal (barrier & deltaic) & adjacent basin & fan facies evolving in response to complete & complex cycles of changing base level & paleogeography
- ⇒ **STACKED CYCLES OF BEDS** – Vertical character of beds from varying depositional settings
- ⇒ **BEDDING** – Internal character including lithology, geometry, sedimentary structures, & fauna
- ⇒ **ALLOCHEMS** – Lithological components, their cementation & diagenesis

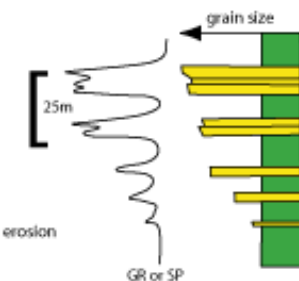
Gamma Ray Log Response & Depositional Setting

DELTAIC & FLUVIAL SETTINGS

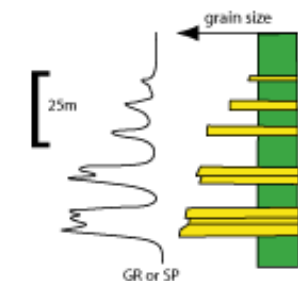
CHANNEL-POINT BAR
alluvial or fluvial



DELTA BORDER PROGRADATION

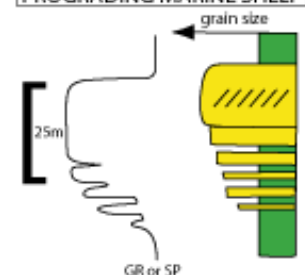


DELTA BORDER TRANSGRESSION



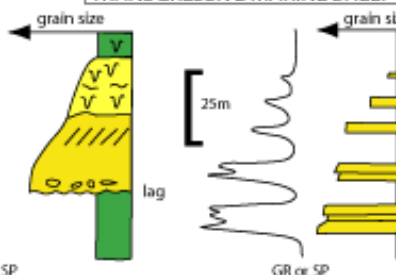
CLASTIC MARINE SETTINGS

PROGRADING MARINE SHELF



PROXIMAL

TRANSGRESSIVE MARINE SHELF



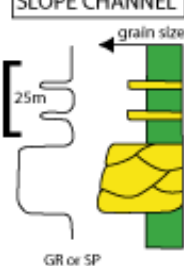
DISTAL



DEEP SEA SETTINGS

PROXIMAL

SLOPE CHANNEL



INNER FAN CHANNEL



MIDDLE FAN CHANNEL



SUPRA-FAN LOBES



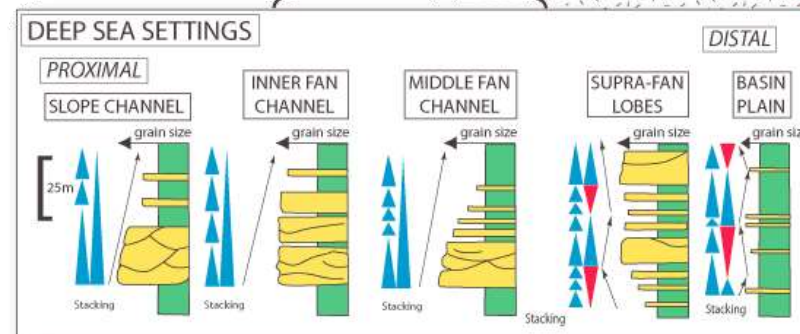
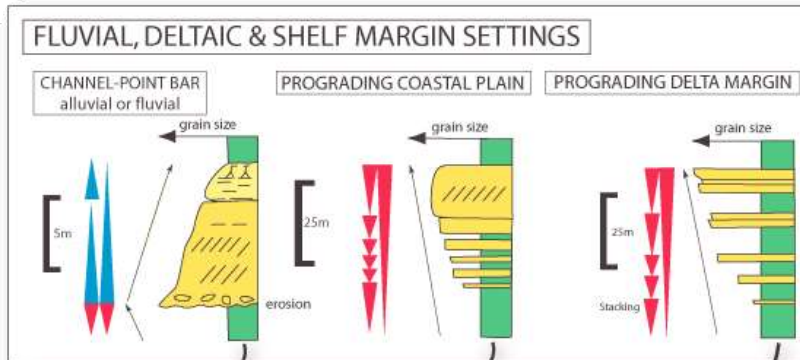
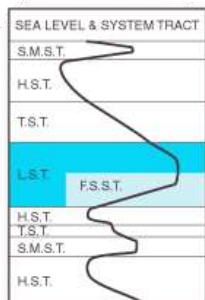
DISTAL

BASIN PLAIN



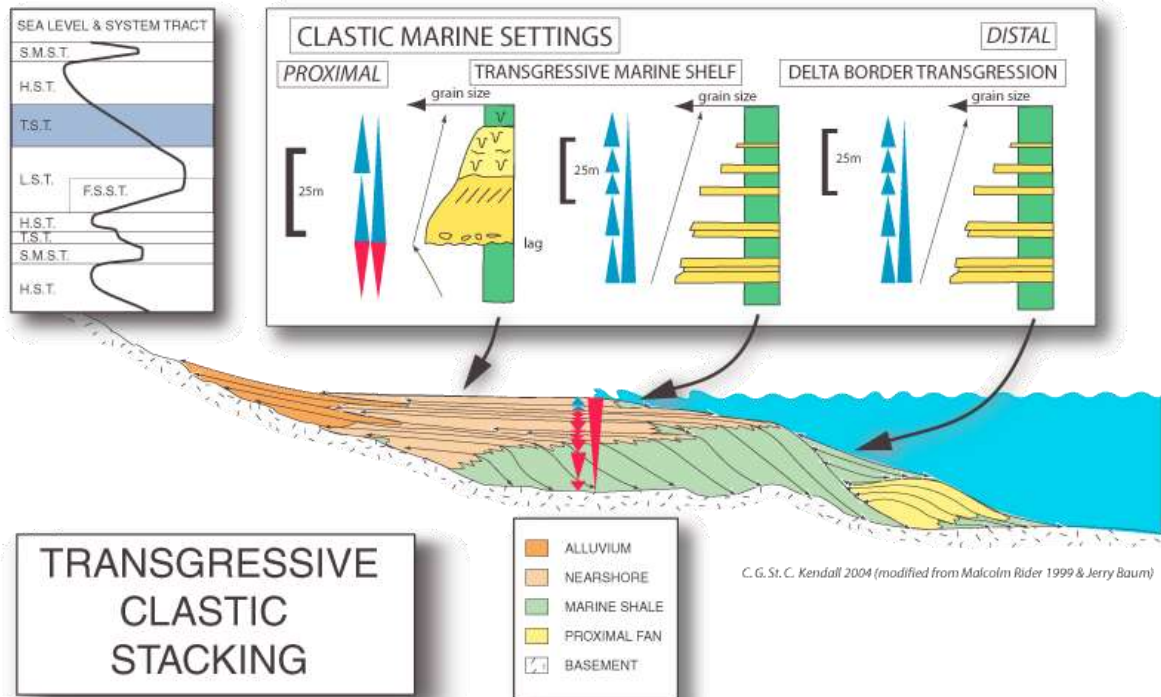
Clastic Sequence Stratigraphic Hierarchies

LOWSTAND CLASTIC STACKING



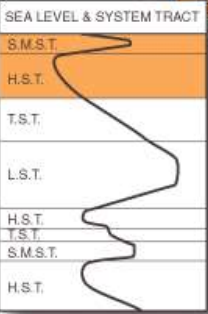
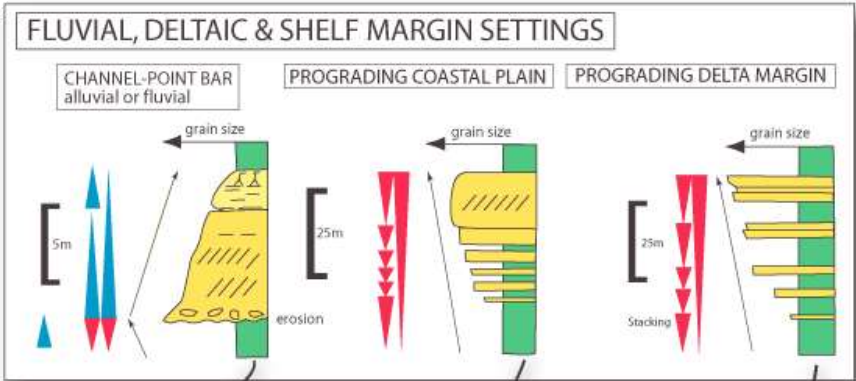
C. G. St. C. Kendall 2004 (based on Malcolm Rider 1999 & Jerry Baum x-section)

Clastic Sequence Stratigraphic Hierarchies



Clastic Sequence Stratigraphic Hierarchies

HIGHSTAND CLASTIC STACKING



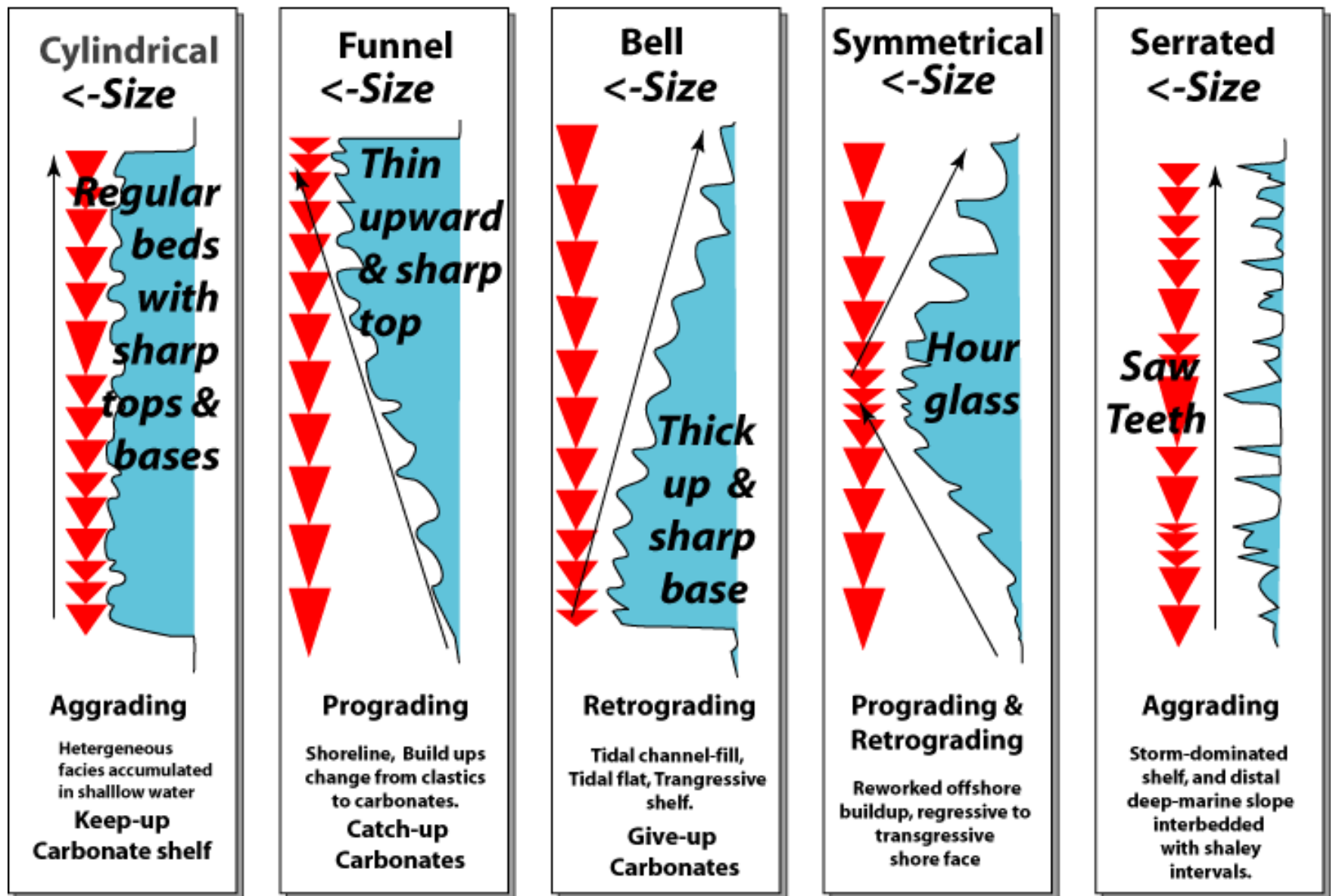
C. G. St. C. Kendall 2003 (modified from Malcolm Rider 1999 & Jerry Baum)

Clastic Sequence Stratigraphic Hierarchies

CARBONATE SEQUENCE HIERARCHY

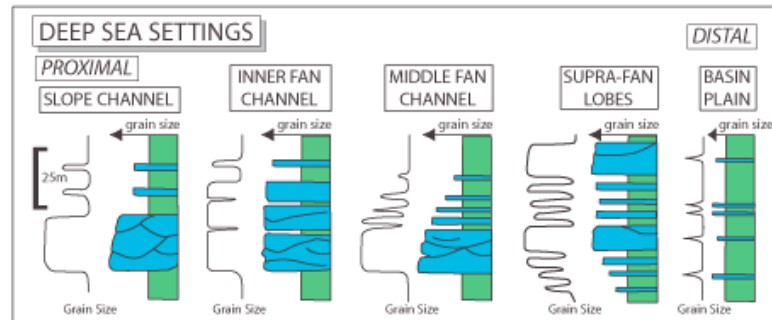
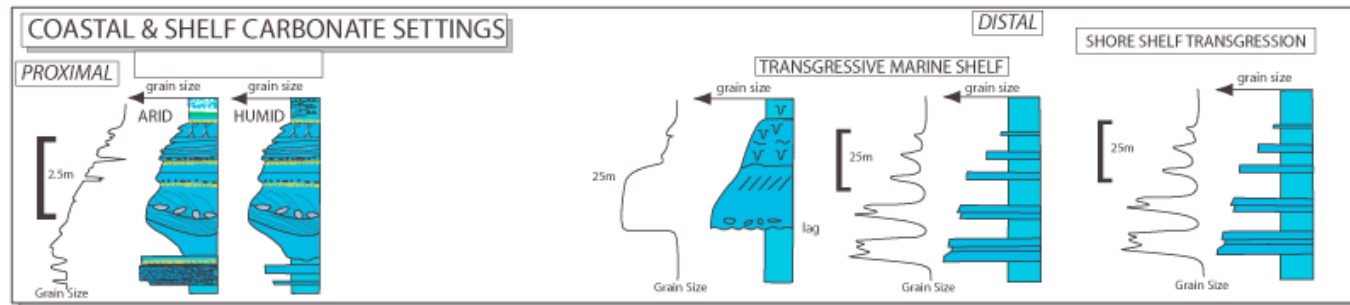
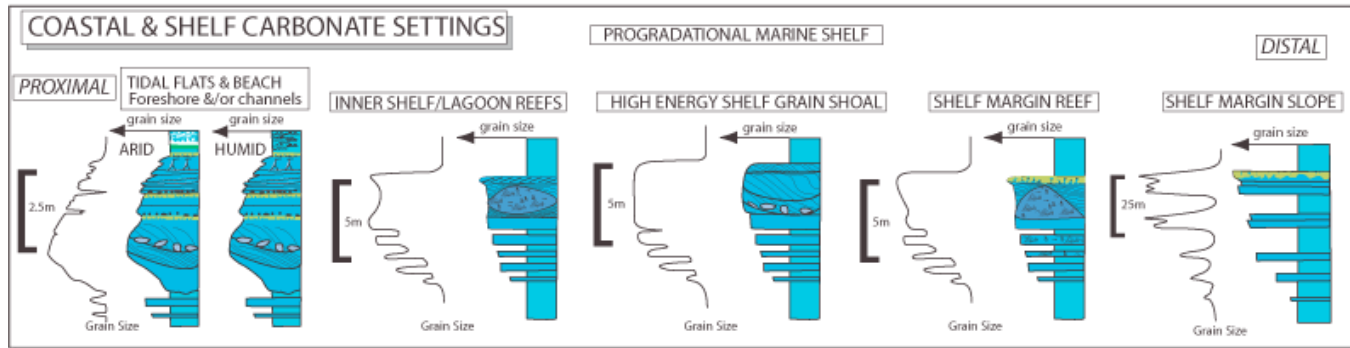
- ⇒ **SHELF COMPLEX** – Mix of shelf, shelf margin & adjacent basin facies evolving in response to complete & complex cycles of changing base level & paleogeography
- ⇒ **MARGIN COMPLEX** – Shelf, shelf margin & adjacent basin facies evolving in response to a cycle in changing base level
- ⇒ **STACKED CYCLES OF BEDS** – Vertical character of beds from varying depositional settings
- ⇒ **BEDDING** – Internal character including lithology, geometry, sedimentary structures, & fauna
- ⇒ **ALLOCHEMS** – Lithological components, their cementation & diagenesis

Carbonate Stacking Patterns - Generalized Variations in Grain Size

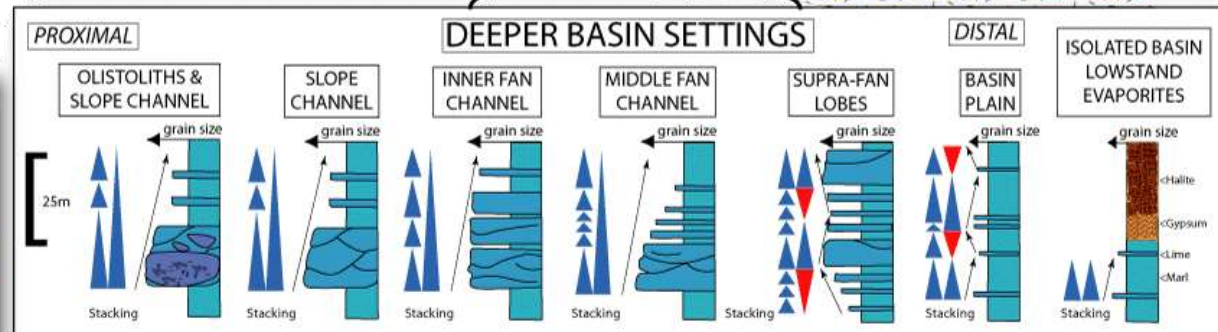
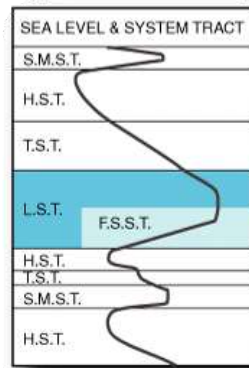
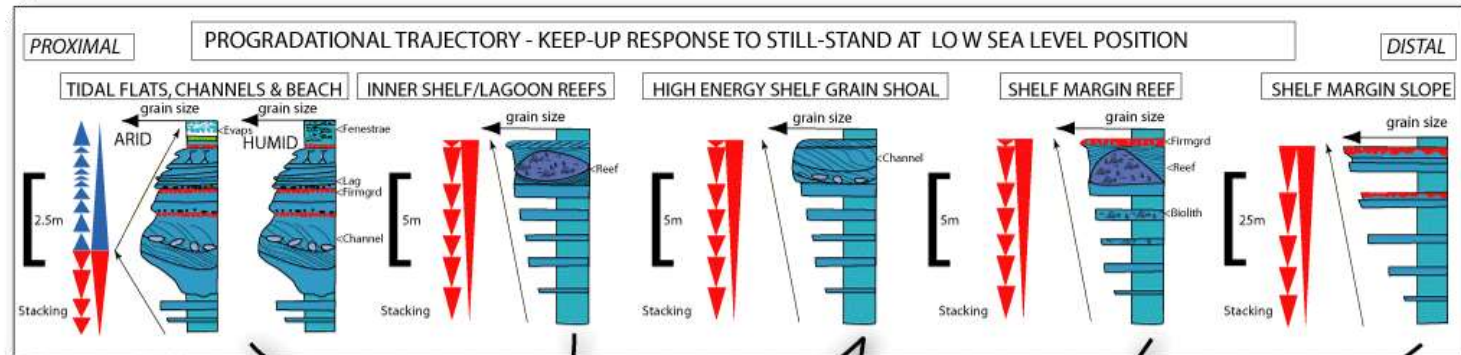


1st Sequence Stratigraphic Hierarchies

Grain Size & Depositional Setting



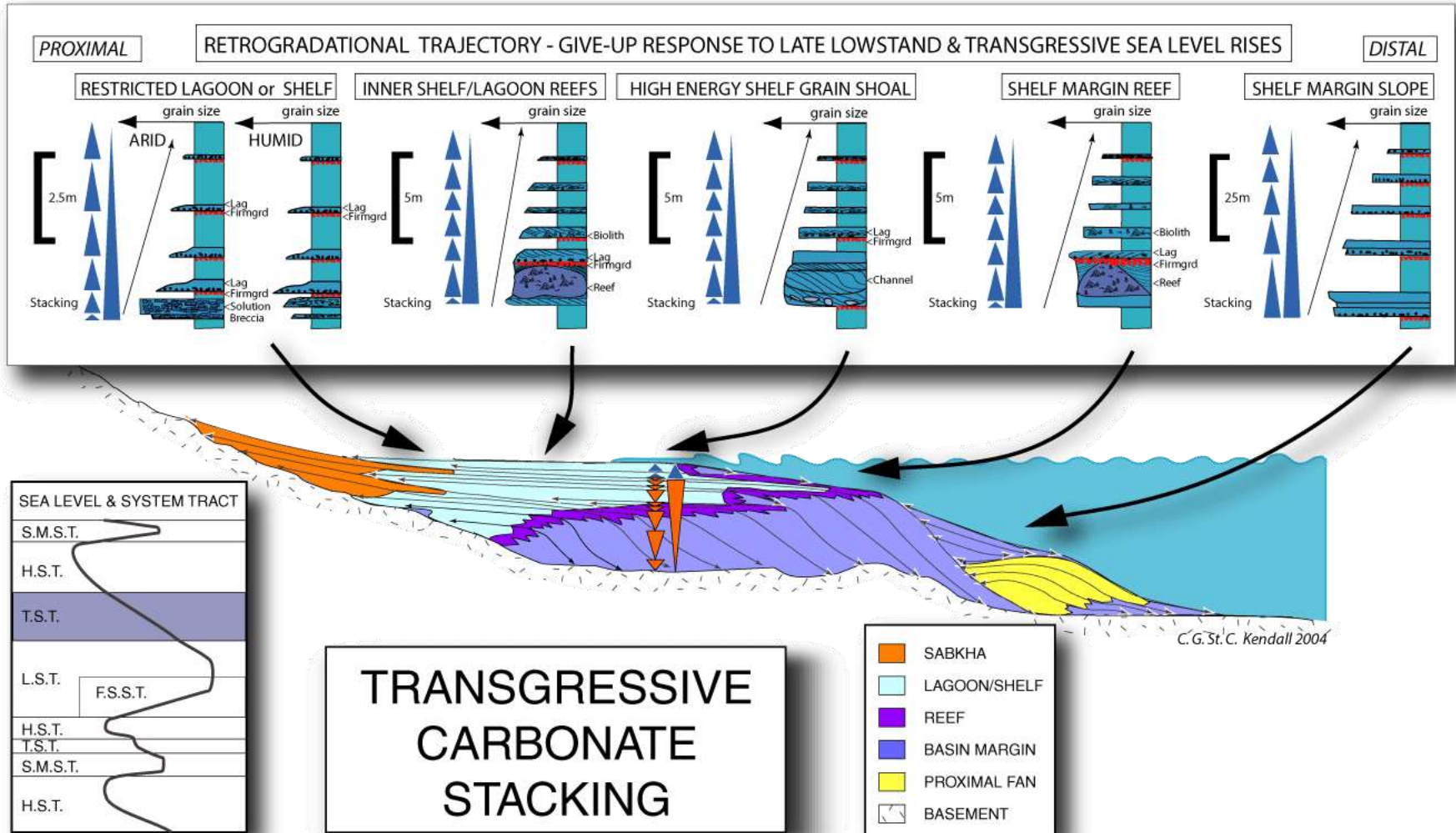
1st Sequence Stratigraphic Hierarchies



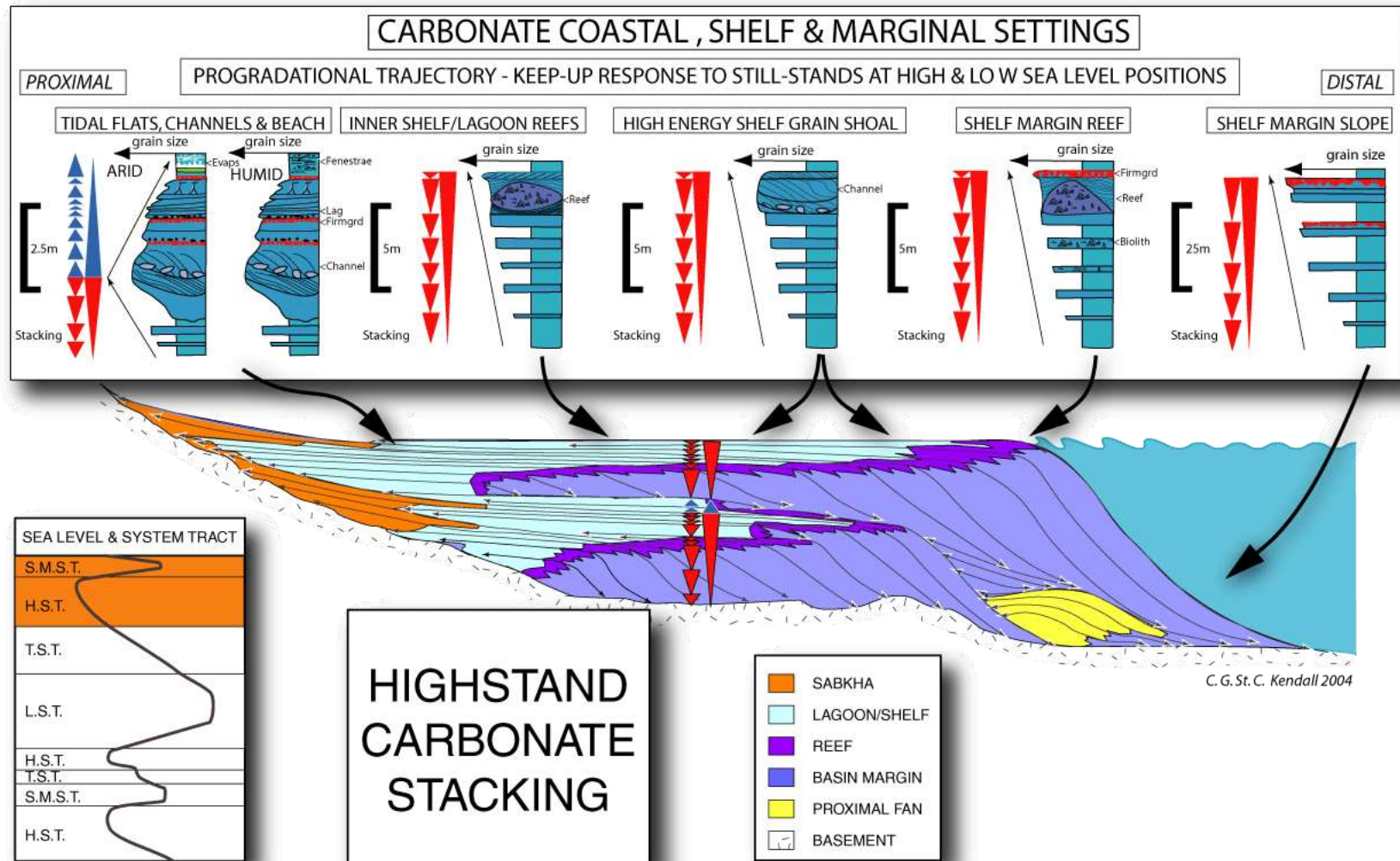
**LOWSTAND
CARBONATE STACKING**

C. G. St. C. Kendall 2004

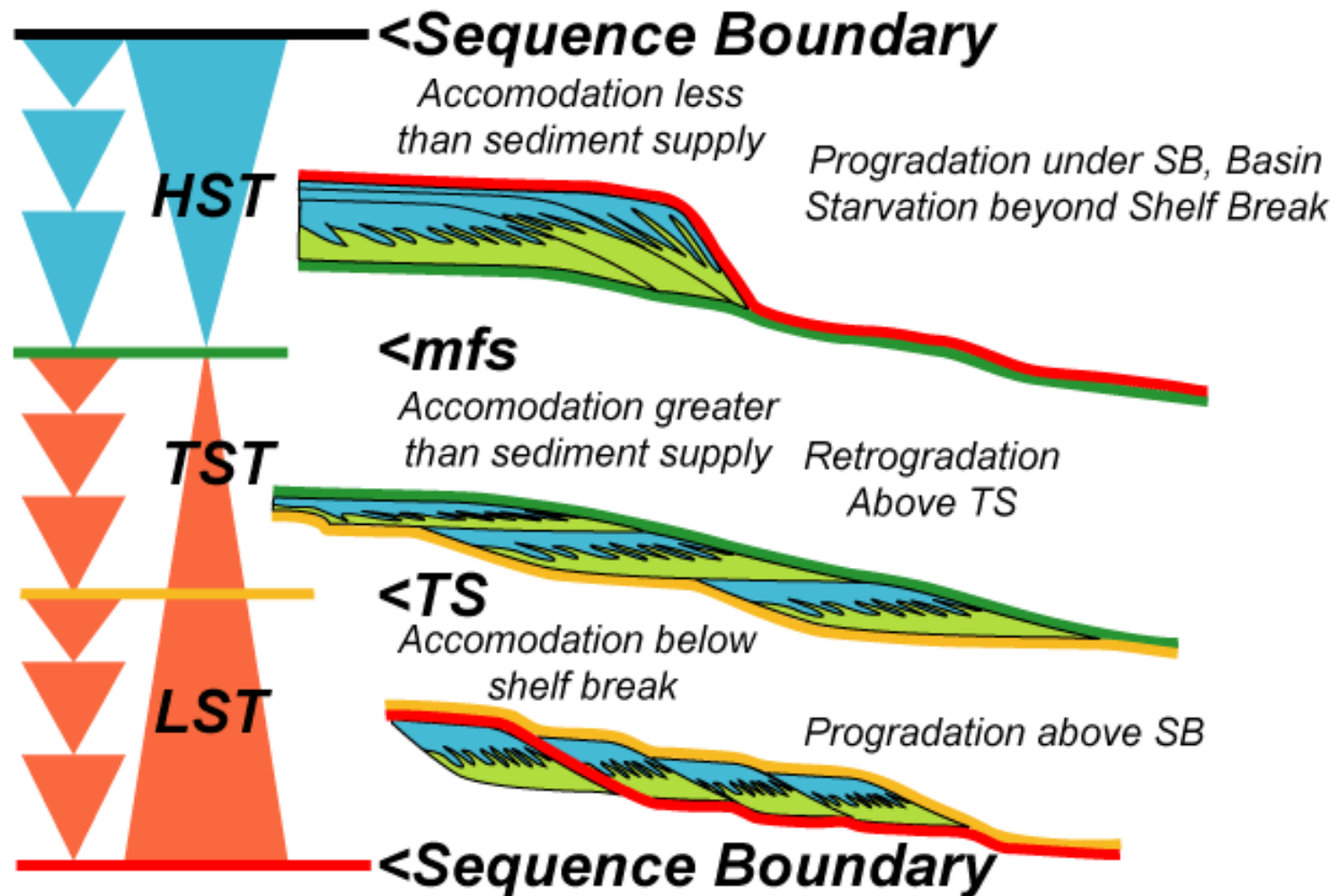
1st Sequence Stratigraphic Hierarchies



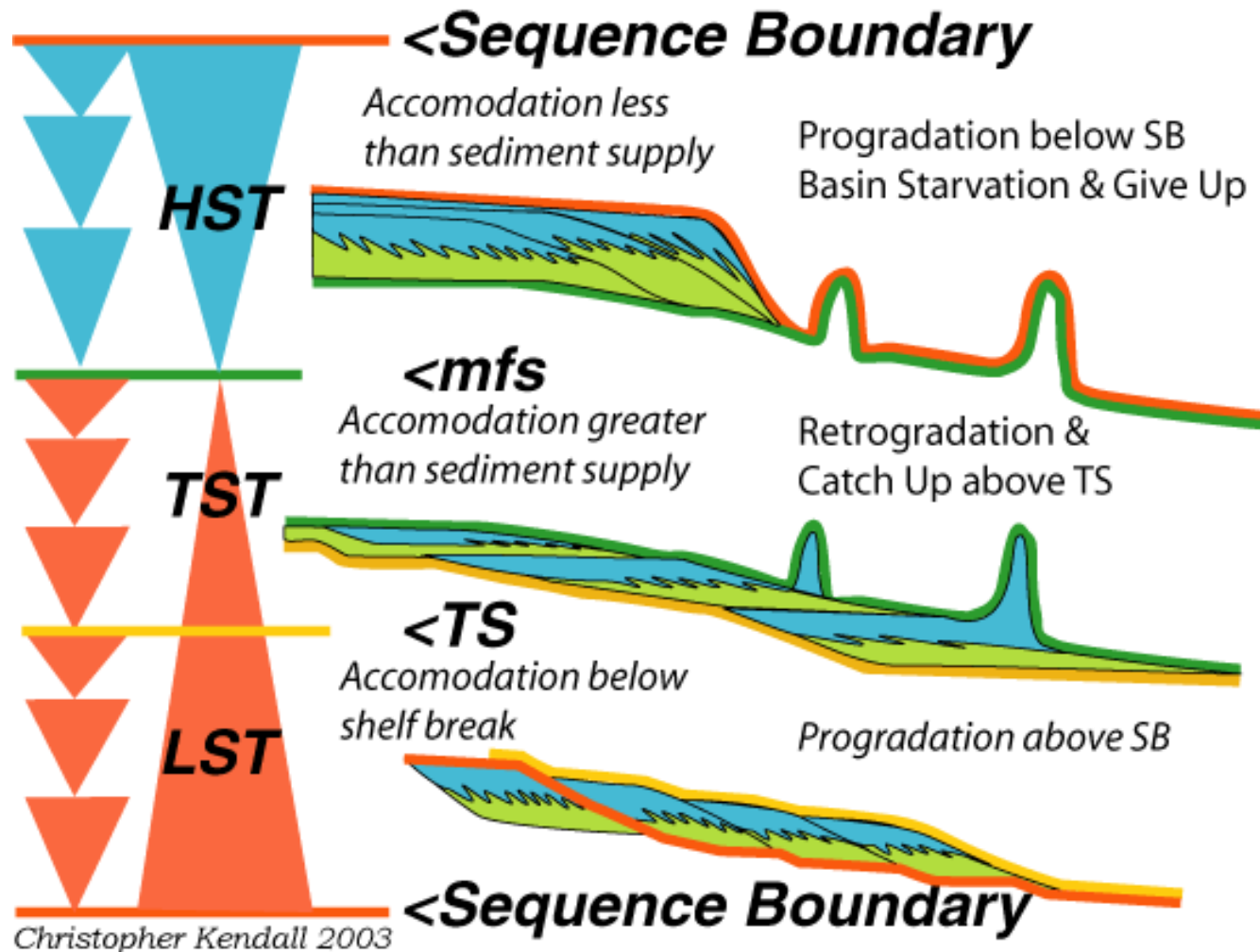
1st Sequence Stratigraphic Hierarchies



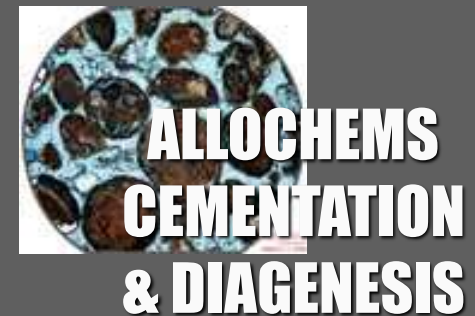
Lst Sequence Stratigraphic Hierarchies



Lst Sequence Stratigraphic Hierarchies



Hierarchy of Carbonate Shelf Architectural Elements



Lecture Ends!!

⇒ And so to lunch



"Sequence Stratigraphy – Basics"
C. G. St. C. Kendall

